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CONTENTS

Synchronization of a Motor Response with an Anticipated Sensory Event.....NEIL R. BARTLETT AND SUSAN C. BARTLETT 203

Toward Empirical Behavior Laws: I. Positive Reinforcement.....DAVID PREMACK 219

A Functional Analysis of Authority.....J. STACY ADAMS AND A. KIMBALL ROMNEY 234

On Discrimination Experiments: I. Two Logical Structures.....MAX WERTHEIMER 252

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THE PSYCHOLOGICAL REVIEW

SYNCHRONIZATION OF A MOTOR RESPONSE WITH AN ANTICIPATED SENSORY EVENT [1]

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Time is a common dimension for specifying either stimuli or responses, and so it appears often in psychological studies on one of the coordinates of the graphical results. This paper puts time on both the abscissa and the ordinate for some extremely simple behavior. Because the resulting picture for short time intervals appears to be in accord with a simple descriptive theory of some factors governing the timing of a response, the report might be categorized as related to the perception of time itself. From the study it appears that a duration of 0.5 sec. may be even more interesting to psychologists than it has already become as the optimal temporal delay between conditional and unconditional stimuli in conditioning and as the minimum separation required between sensory signals to which independent responses must be made.

The work grew out of a concern with the factors responsible for the variation in simple reaction times. In some of our earlier work (Bartlett & MacLeod, 1954), dealing with highly trained *S*s responding to conspicuous signals to which they were fully alerted, standard deviations for samples of reaction times fell in the range from 8 to 20 msec. It was demonstrated how variations in the signal and in the sensory mechanism systematically change both the duration of the reaction time and its variability. But there was a nagging question as to whether the variability for the optimum conditions might have been reduced to a still lower level if one could somehow have modified this typical reaction-time experiment by eliminating *S*'s uncertainty as to when the stimulus was to appear. The rough model guiding our thinking was the oversimplification familiar to all who read elementary textbooks: variation in motor response, in sensory processing, and in some central processing. "Central process" of course includes the usual neurological ideas

[1] This research was supported by Contract NONR 1784(01) between Hobart College and the Office of Naval Research. The authors are grateful for the assistance rendered by many people. Some contributions are noted later in the paper. For general assistance, especial credit is due Dorothy Calingaert and Alice Dickerson. The authors formerly were on the staff of Hobart College.

of central neurones and synapses, but also is a vague enough concept so that one can generously incorporate into it the element of stimulus uncertainty. Whether one regards this as a four-element or three-element model does not matter much. It suggests ways for assessing contributions to the total variance in the time required for a simple reaction.

We proposed to measure reaction times independently of the variation in sensory processing, with *S*'s uncertainty reduced to a minimum. We could not separate the two experimentally because, when *S* is fully informed as to when a stimulus is to be delivered, he reacts independently of its sensory registration. Instead of waiting for the signal and reacting to it, he tends to react simultaneously with its delivery. He anticipates, in short. In any case, measures of error in synchronizing, if appropriate care were taken to ensure that as much information as possible was available to *S* on the timing of the stimulus, should afford measures of variation independent of the random variations in the sensory mechanism. Perhaps, too, some manipulation of the timing of stimuli might permit one to separate out of the "central process" concept a notion of the contribution of *S*'s uncertainty to the total variance. The factor of *S*'s uncertainty might be tied to the length of the interval. Data on attempts to synchronize with one of a series of sensory events repeated at regular temporal intervals were needed. Such was the reasoning at the beginning. As will be apparent in the results, this reasoning was useful for providing a framework for the research, but the data did not reveal the expected reduction in variability.

One would suppose that questions of how well *S* can synchronize and how well he can anticipate the end of temporal intervals can be settled by a trip to the library. There are excellent bibliographies of studies by psychologists interested in music, for example, and the perception of rhythm and time is a classical topic. We will not digress here on the fruitlessness of the library research, nor on the reasons in psychological history that might account for it. Of all the studies examined, only Dunlap's (1910) report is of special interest.

He delivered trains of auditory or visual stimuli with various fixed intervals ranging from ¼ sec. to 1 sec. between the stimuli. After listening or watching a train until he felt prepared, *S* tapped a key so as to synchronize with the signals. Motions of the key were traced on a kymograph. Dunlap computed the average error in trains of repetitive responses and measured the mean variation, two indices which he reported independent of each other. Despite considerable difficulty in holding his kymograph to constant speed, some interesting observations were collected. The error indices varied with the interval between stimuli, though the nature of the relationship between error and interval is not clear. The mean variation for Subject D—Dunlap—with auditory stimuli was 16–17 msec. for the most rapid rates. Then Dunlap offers some additional observations that are surprising, and that appear to have been lost until recent years when "tracking" problems mentioned later in this paper were pursued. For some *S*s a rate of four auditory stimuli per second was too fast, and for visual stimuli, three per second exceeded the limit for responding.

Rate Limit for Discrete Sensory Registration

Taubman (1954) has shown eight per second to be the approximate limit at which brief auditory signals can

be received and counted accurately. Higher rates can be counted only if the total number delivered in the train is low. With brief visual stimuli the rate limit is still lower than that for auditory. The implication is clear: Synchrony with one of a series of sensory events becomes reduced to a random performance when temporal intervals are very short, and, further, sensory mode probably sets the rate limit. Turn the statement around and, however time perception is treated, it follows that there is a limit on temporal perception, and this limit is dependent on sensory mode.

Motor Rate Limit

The motor units for executing responses have upper limits for the rates at which movements can be repeated. The limit depends upon the unit. Articulatory movements with the tip of the tongue, as in pronouncing "tat, tat, tat," do not run above 8.2 per second (Miller, 1951). The upper arm and the feet cannot be moved with a frequency as high as that for the finger (Wuest, 1947), nor the jaws as fast as the tongue (Miller, 1951). Dresslar (1892) showed that taps by a single digit occasionally hit rates as high as 10.5 per second, but the normal limit is about 8.5 (Seashore, 1938), with long practice carrying the score only to 9.3. What fixes the upper limit is not known. Because the finger may be moved at a faster rate by electrical stimulation (Craik, 1947), it is commonly believed that the upper frequency limit may be explained in terms of the neural control. In short, behavior, which after all must somehow be exhibited if it is to be recorded, involves movement of masses, and those movements can be executed only at the garden-variety slow rates peculiar to living organisms. Incidentally, note that the maxima are of the same order as the limits for perceiving discrete stimuli.

Tremor Effects

The execution of a digital motor response is complicated by tremors. The same kind of complication probably obtains with other motor units. The pitch vibrato reported by Seashore (1938) to range from 5.9 to 7.8 per second in singing reflects a tremor either in the activity of the larynx or control of the breath, or both. Forearm tremors at a rate of about 13 per second have been described (Dresslar, 1892). The point is that tremors are found in motor units. Finger tremors have been studied most extensively. The finger typically exhibits a frequency range from 5 to 500 cycles per second (Hauty, 1954). The highest percentage of occurrence falls at the 40-per-second level, but, with frequency and amplitude inversely related, the large and slower tremor in the range from 5 to 12 per second predominates and appears to have superimposed upon it some smaller and faster tremor. When digital responses are made, the type most frequently observed is a blending with the tremor (Travis, 1929). The tendency for the response to occur in phase with the tremor suggests to Lansing (1957) that the excitability processes operate at a low level, possibly in the spinal motor pool. Whatever the physiological basis, if the tremor in a motor unit is slow, and if phasing with the tremor characterizes the reactions of the unit, the effect upon the variability of synchronizing reactions, or indeed upon the variability of any motor reactions to sensory stimuli, whether anticipated or not, would be substantial. In summary, then, not only must one reckon with some motion impedance pointed to earlier, but there is the added factor that movements are executed against

a background of smaller motions and of the substrate of neural excitation implied. All of these factors somehow continue to produce the variation in motor response referred to earlier.

Motor Responses to Cyclic Visual Signals: "Tracking"

Tracking is a complex behavior requiring continuous motor output while the *S* monitors sensory events. Recently some observations have been reported by Klemmer (1956) indicating that certain simple eye-hand coordinations become difficult when stimuli are repeated as fast as twice per second. Similarly, Noble, Fitts, and Warren (1955), in their study of pursuit tracking (holding a visual target aligned on a cathode-ray oscilloscope by compensating manually for sinusoidal variations in its position), found that *S*s deteriorated at surprisingly slow frequencies. Though there were differences among *S*s in the limiting frequency for holding synchronization, in general they could not perform well with signals moving faster than about two cycles per second. We have included the preceding observations only as a precaution against extrapolating from data on attempts to synchronize with a single event in a series to complex behavior such as tracking.

Some Generalizations and Predictions

In summary, one is left with a generalization: Responses can be synchronized with anticipated events with fair precision. Musicians and aerial acrobats have some skill in this regard, even though it appears there are no data on the limits of their skill. Single temporal intervals and rhythmic patterns are reproduced, and though investigators differ markedly in the magnitude of errors reported, the error, at least with moderately brief intervals, is only a small fraction of the interval (Ruckmick, 1913; Seashore, 1919; Woodrow, 1951).

Second, there are some generalizations to qualify the first. Sensory channels can register events only at low rates. If *S* is required to count them, for example, auditory stimuli are not treated accurately at a rate faster than about eight per second. Furthermore, motor units show limits for the speeds at which movements can be repeated. At least to one accustomed to think in terms of the speeds of some common household and laboratory machinery, man's motor appendages operate at a surprisingly low rate. Again, at least some motor units exhibit slow tremor, and, in studies of digital responses, the responses have been shown to tend to occur in phase with the tremor.

The initial question was one of the magnitude of the error. But the question immediately turns into a number of additional queries: Whose error? With what motor responses? With what signals? With what intervals between signals? After what degree or type of training? But though additional questions are raised, there are a few hypotheses from the background of related research to offer some tentative answers.

First, as in studies of the reaction speed to single stimuli (Teichner, 1954), considerable variation from person to person should be expected and a large amount of training found necessary before an *S* performs at his best. Second, one should perform better with motor units suited for fine articulated movements: for example, a finger movement might permit a better score than a foot movement. Third, if the interval between stimuli is very brief, synchronization should become impossible, with responses falling at random throughout the interval between signals. Moreover, the limiting brevity

might vary depending on the sensory channel. The ear might permit shorter intervals than the eye. Finally, for longer intervals the error in synchronization should come to depend less upon the sensory or motor modes, and more upon "memory" (or "centralmotor" or whatever other arbitrary name one can assign to the process) for repeating time intervals.

With some simple assumptions, the error limits can be predicted in a general fashion. First, when the pace for the sensory events is too fast, performance is random. Responses fall in a rectangular distribution throughout the interval, and so, as a simple mathematical treatment for such distributions demonstrates, the standard deviation (SD) for a large sample accordingly becomes simply the interval divided by the square root of twelve. Samples will have a standard deviation approximating this chance index, sometimes falling above and sometimes below, depending on sampling error. If E denotes the standard deviation in seconds and I the interval, the value of E is defined as

$$E \cong I/\sqrt{12}. \qquad [1]$$

For slower rhythms the ratio of E to I will decline, but E will not fall below a limit depending, if not upon the sensory-motor coordination mode, at least upon the motor mode. In the simplest case, where M denotes the motor time limit

$$E \geqslant M. \qquad [2]$$

Finally, for very slow rhythms the "memory" factor predominates. Though the Weber relationship is probably too simple for expressing the relationship between E and I, it is postulated as a first approximation. Where C denotes the "central" or "memory" Weber quotient,

$$E \geqslant IC. \qquad [3]$$

If this reasoning is sound, a graphical display for the standard deviation E plotted on the ordinate against I on the abscissa should show that as I increases from zero, E first increases in accordance with Equation 1 until I is sufficient to permit identification of discrete sensory signals. For larger values of I, E would decline and possibly hold to the value M, until I attains a value of approximately M/C. Thereafter E again increases, always remaining above the value IC. If one may speculate with abandon, it is possible to suppose that William James, with his concern for the specious present, might have been interested in knowing the value of $I = M/C$.

PRELIMINARY MEASUREMENTS

Method and Equipment

Recordings were made of the precision with which one can throw off the "count" toggle switch of a Berkeley Model 410 electronic counter so as to synchronize with the slam of the mechanical registers of the machine. A train of pulses was fed to the machine at a constant frequency. Every thousandth pulse excited an electronic relay which operated the mechanical registers. The S attended to the regular beat from the mechanical register while grasping the toggle switch between thumb and forefinger. Then, when he had listened to enough beats so that he was satisfied he was following the rhythm, he pressed down on the toggle switch to stop the count as closely as possible upon the beat. The mechanical register indicated how many thousands of pulses were fed into the machine; the last three digits of the pulse count were read from three banks of decimal counting units. Thus with an audio oscillator input of 1,000 cycles per second the mechanical register slammed repeatedly at intervals of 1 sec., and when the count switch was thrown off the decimal counting units showed, in thousandths of a second, the time that had elapsed since the last activation of the relay. If it is assumed that the relay circuit to the mechanical register and the

mechanical register itself operated instantaneously, the count appearing on the bank of lights constituting the decimal units is a measure of the error in synchronization. For example, if the count is 003, the attempt to synchronize with the anticipated sound is 0.003 sec. tardy, or if the count is 981, the attempt is 0.019 sec. early.

Except for a few exploratory samples collected at other frequencies, the frequency used was 1,200 cycles per second. The interval between sounds was thus 0.833 sec., and error was read in units of twelve-hundredths of a second.

Magnitude of the Error

Data were collected on one *S* (B), who had participated in the earlier visual reaction experiments and who had played with the machine in this way on many occasions during the preceding three years. Single samples of 50 readings showed distributions that do not differ significantly from normal probability: the means did not deviate more than 10 msec. in either direction from synchrony, and the *SD*s for samples ranged from 20 to 30 msec.

Two musicians each contributed 50 readings. Both are accomplished artists, and of particular interest here, they also enjoy some distinction for their duo piano performances, so presumably have a fair degree of skill in synchronizing. Their switch snapping showed a mean error and scatter comparable to that for B. However, particularly as reflected in the mean error, the initial samples of fifty were not quite so precise.

Twelve student volunteers likewise were tested. After five demonstration trials, with *S*s being told their scores, a sample of 25 readings was recorded for each. As in preceding tests, *S* was allowed to attend to as many noise strokes as he wished before throwing the toggle switch. Inasmuch as the twelve were novices, it may be of interest that of the 300 responses recorded, most were attempts to synchronize with either the fourth or fifth stroke. Only two attempts went beyond seven. Mean errors in the samples ranged from 0.163 sec. early to 0.046 sec. late, with standard deviations varying from 0.019 to 0.079 sec. The mean of the twelve standard deviations was 0.037 sec. Some tended to throw the switch at the proper instant but with much variation from trial to trial; others were consistently early, one was inconsistent and early, and so on.

The *S*s were instructed to throw the switch upon whatever stroke they wished, and there was some variation in the number attended to before responding. Hence it appeared that in future tests some might throw a switch without enough information from the stimuli. It therefore seemed that the instructions should be modified so as to require *S* to listen to at least 3 or 4 strokes before responding. If such instructions were used, data for attempts on the third beat, for example, might be discarded as involving insufficient stimulus information. To learn whether *S* could pick up enough from two strokes to respond successfully upon a third, the 12 *S*s appeared for a second series of tests, this time with instructions to throw the switch to coincide with the third.

Results

The results were inconclusive; the *t* test showed a slight improvement in the second series, but this well might have been a random variation, not to mention the possibility of its being attributable to practice. On the basis of these findings it was decided that in subsequent testing the original instructions would stand: *S* would be allowed to elect the stroke upon which he attempted to synchronize.

Having established the general magnitude of the errors with 1 highly trained subject, with 2 musicians, and with 12 undergraduate novices, and having a demonstration that the instructions were workable, the equipment was improved to afford a more conclusive experiment.

EXPLORATIONS OF INTERVAL, MOTOR MODE, AND SENSORY EFFECTS

Apparatus [2]

Changes were made which furnished additional means for stopping the count and an improved presentation of repetitive auditory stimuli. The lead from the last decimal counting unit to the relay circuit of the mechanical register

[2] The additional circuitry was designed and assembled by John R. Graham of Hobart College.

was disconnected from the relay circuit and fed through an inverting amplifier into a cathode-coupled one-shot multivibrator. The negative pulse from the multivibrator led to a separate scale of 10 (Berkeley Model 700A), where as many as 9 pulses could be counted. The positive pulse was led through a cathode follower and impedance-matching transformer to earphones (Permoflux Type HD-1). When pulsed in this fashion, the phones registered the sound as a sharp click. Attenuator tests with normal operation of the gear showed a reduction of approximately 40 db. required for making the click inaudible.

A gated amplifier (6AG5, triode connected) was inserted between the audio oscillator and the Berkeley Model 410 counter. The gate could be closed (terminating the count) either by pressing on a normally closed microswitch or by uttering a plosive sound into a microphone and associated amplifier.

The mechanical switch was a rigid-lever microswitch, Type BZ-2RW80. This switch has a long lever arm. The whole was fitted into an aluminum and wood box 37 cm. × 25 cm. × 4 cm. so that the lever arm protruded through a slit in the top (37 cm. × 25 cm.) surface. By bending this arm it was made to rest parallel with the surface and approximately 7 mm. above it. As bent, the distance from the end of the lever to its fulcrum was approximately 6 cm. A small force applied at the lever end is sufficient to trip this switch; weight tests showed 10 gm. usually to suffice, and 12 gm. to trip it every time. If moved from the position of rest, the end of the lever moved down approximately 5 mm. before the circuit opened. With training, *S* can hold the lever arm part way down so that a remaining excursion of 2 or 3 mm. suffices.

By a system of clamps the box could be secured to a laboratory bench at any angle of choice, or the box could be rested on the floor for pedal operation. For finger operation, the heel of the palm rested on the top surface. For forearm tests, the wrist was held rigid, and the medial surface of the forearm rested on the edge of the wood surface. Again the switch was operated by pressure from the finger pad against the lever. For pedal tests, the box was placed on the floor and the switch closed by pressure from the first toe. For foot tests, the heel rested on the wood surface, and for toe tests the ball of the foot remained on it.

Preliminary Observations

Finger reactions of 19 students to a 0.83-sec. click interval furnished an estimate of individual differences after a short training period and helped establish an index for the effects of training.

Five preliminary trials were given each *S* for familiarization with the task and for checking positions of the hand. Then a series of 20 trials was run off, *S* being told after each trial the extent of his error and whether tardy or early. Incidentally, throughout all the experiments with this equipment *S* had one clue to the success of any trial. If he heard the click with which he attempted to synchronize, he either made a perfect score or was late; if the click was not heard, he was early. Following a rest, another block of 20 trials was run. This procedure was continued for four blocks. Then a fifth block was run, but, for the fifth, *S* was not informed of his score.

Significance (t) tests show the improvement between the first and fourth training series, as reflected in both the constant error and the standard deviations, to be dependable. The mean of the *SD*s was 0.065 sec. in the first

series and 0.051 sec. in the fourth; the mean of the constant errors −0.046 sec. in the first, and −0.006 sec. in the fourth. The fifth test series, with no word given *S* on his score, did not differ significantly from the fourth series. The data demonstrate a point that is obvious to one watching beginners: A long time is required to master the task, simple though it appears to be. In this situation, *S*s tended to respond too soon, especially at the beginning. One of the most noticeable effects of the training was the reduction in the number of radical "gun-jumping" errors.

The scores derived with this new method of testing are more variable than those obtained with the toggle switch. A different group of *S*s was used, and the task was different; so the point should not be labored. But neither should one ignore the possibility that in the early stages of training a free finger tap on a lever is more erratic than snapping a toggle switch held between thumb and index finger.

Reliability, as reflected by correlation coefficients for error indices from one series of samples to another, is low for samples of twenty trials. For example, the rank-order coefficients for the correlation between variances (square of constant error plus square of *SD*) in the first training series and those in the fourth is 0.51. For total variances in the first and the final or test series rho was 0.48. Especially at the beginning, an individual fluctuates widely from one trial to another, and hence from one small sample of trials to another. A large number of tests must be conducted before reliance can be placed on an error index for the performance of one attempting to synchronize.

These preliminary observations confirmed what had already become fairly clear. The elucidation of such factors as interval time and response mode must be based upon a large number of trials with well-trained *S*s. Gross effects might be revealed in small samples of 15 or 20 trials. But many samples of small size, or conversely, one sample of many trials, would be required at every test point for tracing any but the most gross effects. Because *S*s tend to lose interest in their work with repeated trials involving one tempo, and because on the other hand a few practice trials are useful to help *S* establish the tempo before recordings are made, the most economical and perhaps most valid method for collection of data is to accumulate samples of moderate number.

Factorial Experiment on Motor Mode[3]

Method. A plan for conducting blocks of tests involving voice, finger, hand, and toe was developed. The factorial design involved four blocks for each day, each block comprised of twenty successive trials using a particular response mode. Block sequences followed on the four days of the tests were, respectively, ADBC, CBDA, BACD, and DCAB. After several days' training on each of the modes of response, three *S*s were run through the schedule of tests. As before, the interval between sound stimuli was 0.83 sec.

One response mode was voice. To execute the vocal response *S* first inhaled moderately, then, with mouth open, held the breath, while the auditory stimuli were delivered to him. By sudden forced expiration,[4] much as in a sharp cough, he uttered a plosive sound into the microphone. The second mode was a

[3] Factorial designs and statistical procedures were developed by Robert L. Beinert of Hobart College. He also performed the computations in the various analyses.

[4] The anatomical substrate in this response is very complex. Besides violent contraction of elements in the larynx, there must simultaneously be relaxation of the diaphragm, possibly some activity of the internal intercostal and transversus thoracic muscles, and most certainly the contraction of four abdominal muscles. The response mode was chosen on account of its complexity.

tap with the index finger, the heel of the palm resting on the top surface of the switch box. The third was a forearm movement, with wrist rigid. The fourth involved movements with the first toe, the ball of the foot resting on the top surface of the switch box.

Results. The variance in the error indices for each of the 48 blocks was evaluated by calculating F ratios for parts attributable to identifiable effects. Such calculations were performed for three indices: mean or constant error, standard deviation, and square root of the total variance. In the main, the results are not very informative. For standard deviations, no one of the identifiable first-order variance sources (subject, mode, or day-order) contributed to the variation a degree that is statistically significant. For the mean or constant errors one first-order source (S) and one interaction ($S \times$ day-order) were identified as significant factors in the variation. The calculations with the square root of variance likewise showed a reliable difference in Ss, but nothing else of statistical significance. Detailed inspection of the raw data suggests that these elaborate statistical calculations were pointing to the fact that one S (NB) had two poor days for using his foot and voice.

A summary of the constant error and standard deviation indices is presented in Table 1. Shown are means for the indices in each of the four blocks recorded for each S and mode. Thus the constant errors are based on 80 trials and the standard deviations are the means for four samples of twenty trials each. As before, a negative sign denotes that the average response fell prior to the anticipated event. If the constant error was positive in sign, the average fell after the strokes with which synchrony was attempted. Inspection of these gross results shows that, except for NB's erratic performance with his voice and foot, there is homogeneity among modes and among the three trained Ss in synchronizing with sounds at this moderate tempo.

TABLE 1

CONSTANT ERROR AND STANDARD DEVIATION (IN SECONDS) FOR FOUR MODES OF RESPONDING

Subject		Finger	Hand	Voice	Toe
DC	*M*	−0.007	−0.020	−0.010	−0.003
	SD	0.034	0.032	0.037	0.036
NB	*M*	−0.008	−0.018	−0.046	−0.035
	SD	0.030	0.032	0.043	0.037
RC	*M*	0.002	0.015	−0.005	−0.006
	SD	0.035	0.030	0.031	0.036

Interval Between Signals and Sensory-Motor Mode

Method. Error indices in block samples (each 20 trials again) were determined for six rates for presenting signals and three sensory-motor modes. The sequence for the tests was planned so as to permit an analysis of the contributions to the total variance in the indices for the blocks by S's modes, intervals, interval-sequence, and their interactions. The schedule involved three sequences for testing the intervals, so altogether 162 blocks were compiled.

The rates for presenting signals ranged from very fast to slow. Intervals between stimuli were 0.125, 0.25, 0.50, 1.0, 2.0, and 4.0 sec. The three sensory-motor modes were eye-finger, ear-finger, and ear-toe. Thus comparison of the first two would afford some notion of sensory effects in a sensory-motor coordination involving the finger; comparison of the last two, a notion of motor effects. The headphone click served as the auditory stimulus. For a visual stimulus the flash of a Ne-2 neon lamp, illuminated at the beginning of each interval and lasting for one-tenth the interval, was employed.[5] With fast rates S could not iden-

[5] Specifically, the lamp was one in the Berkeley counter display. A cardboard screen was dropped over the decimal counting bank of lights, with an aperture in the screen permitting S to view the bottom or zero lamp of the first bank. Under the conditions of viewing, the lamp appeared to stop flickering and to be continuously luminous

TABLE 2

MEANS OF CONSTANT ERRORS AND STANDARD DEVIATIONS (RELATIVE UNITS)

Mode	Interval in Seconds	SB		DC		AD	
		Constant Error	*SD*	Constant Error	*SD*	Constant Error	*SD*
Eye-Finger	0.125	−.022	.29	−.139	.29	−.210	.29
	0.25	.182	.28	−.042	.29	−.207	.28
	0.50	−.024	.085	.075	.117	−.021	.071
	1.00	−.045	.060	−.052	.062	−.022	.046
	2.00	−.075	.059	−.042	.041	−.014	.041
	4.00	−.043	.052	−.051	.035	−.016	.039
Ear-Finger	0.125	−.107	.30	−.087	.29	−.068	.25
	0.25	−.076	.163	−.162	.089	−.030	.097
	0.50	−.098	.067	−.067	.046	−.062	.079
	1.00	−.067	.057	−.029	.029	−.025	.039
	2.00	−.051	.044	−.035	.029	−.009	.038
	4.00	−.081	.051	−.057	.040	−.019	.039
Ear-Toe	0.125	−.039	.22	−.245	.28	−.094	.25
	0.25	−.114	.131	−.070	.082	−.075	.083
	0.50	−.133	.068	−.030	.038	−.046	.068
	1.00	−.112	.064	−.036	.040	−.035	.049
	2.00	−.054	.049	−.055	.040	−.030	.040
	4.00	−.044	.054	−.048	.037	−.006	.035

tify the signal with which he intended to synchronize, so consequently there was no proper basis for computing error. An arbitrary convention was adopted: Error was measured as the time to the nearest signal. Thus if the counters read 500 or more, the error was found by subtracting from 1,000; if the number was less than 500, it was assumed to be the error. By this convention no error was recorded as greater than half the interval between signals.

Results. The variance analysis was carried out with scores for each block of trials expressed in relative units rather than in seconds. The analysis showed substantial and statistically significant contributions, at better than the 1% level of confidence, for *Ss*, mode, time interval, and for the first-order interaction between mode and interval. Table 2 presents for each *S* the means for the three block determinations of constant error and standard deviation. To convert the data of this table into seconds, multiply each entry for constant error and standard deviation by the time interval.

Errors are predominantly those of striking the key slightly early. If the signal with which *S* intended synchronization appeared, the attempt was either entirely correct or it was late. Such a cue may have operated to reduce the number of tardy responses. For the rapid presentations, the scatter index (*SD*) is found to be at about the level for random distribution of responses throughout the interval.

Comparison of the data for ear-finger and ear-toe reveals no striking differences for the motor units. In general, the performance with eight signals per

if flashed at about 30 times per second. At the fastest rate employed here (eight per second), a train of flashes was sensed, but *S* could not count them or select a particular one with which to synchronize.

second to the ear (0.125-sec. interval) is about at a random or chance level, then there was a progressive improvement at slower rates until an asymptotic level is reached. DC evidently moves to this asymptotic level more rapidly than the other two *S*s. The trend in standard deviations is highlighted in Fig. 1, showing the mean of the *SD*s for the three *S*s with the ear-finger mode. Extensive data for two other *S*s, collected with slightly different equipment that will be described in the next section, are presented on the display also. Shown on the graph as continuous lines are, first, an upper chance level, at which the relative error is equal to the reciprocal of the square root of 12; second, a curved line denoting a motor (M) limit of 0.018 sec. for absolute time values for the *SD*; and third, some "central" (C) limit of 0.036 for the relative error. These M and C limits are arbitrarily chosen; reference to Table 2 shows, for example, that DC might be assigned a lower C limit. Nonetheless, the general trend is manifest and is in accord with the view presented in the introduction that skill in synchronizing is bounded by three limits: some sensory limitation with very fast stimuli, so that performance

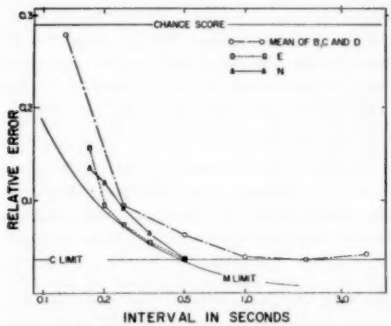

FIG. 1. Relative error (standard deviation) as a function of interval between clicks.

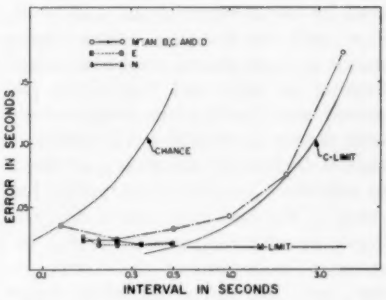

FIG. 2. Error (standard deviation) in seconds as a function of interval between clicks.

becomes more or less random; a motor limit which cannot be exceeded for any perceptible intervals whatsoever; and, finally, some limiting process to memory for longer intervals.

Figure 2 is another display of the same data, but this time with the ordinate showing the error (means of standard deviations) in seconds, rather than as relative to the interval. This picture of the data, particularly as supplemented by the observations on *S*s N and E to be described later, underscores the point that as intervals between stimuli are made long enough to lift the imposition of chance scores by the sensory system the error in synchronizing remains fairly constant for further increases in the interval until the value M/C is attained.

Comparison of eye-finger with ear-finger results reveals a superior performance with the auditory signals for rates of four per second and possibly even two per second. Figure 3 displays the trend in the standard deviations for the eye-finger mode. The continuous lines for the M and C limits are the same ones chosen arbitrarily for Fig. 1, and so afford comparison with the ear-finger data. Chance performance remains, of course, the reciprocal for the square root of 12. As meas-

ured by the average of the scatter indices with the three *S*s, relative error stands at about chance level with lamps flashing at eight and four times per second, and then declines progressively with slower rates until finally performance is limited by the ability of the *S* to reproduce long time intervals. The range of the fast rates, where the eye-finger coordination appears to fail because of limitations of the visual system, and the range for slow where memory errors become critical, almost overlap so that at no rate does the coordination appear to be limited by motor effects.

Intermediate Intervals: Comparison of Visual and Auditory Signals

Methods. In the last section there were only two intervals sampled in the region between ½ and 1 sec. The tests with the two intervals were insufficient to show exactly the functional relationship between synchronization error and the stimulus rate, but nevertheless they demonstrated that the function depends upon the sensory modality. The differences between the auditory and visual data were not accidents of statistical sampling. Perhaps they could be attributed to the point that the visual signal was exposed for a tenth of the interval, whereas the auditory was a brief click. There was also the possibility that the magnitudes of the sensory response to the two types of stimuli might be different. An exploration over the intermediate range of stimuli with signals whose duration and sensory magnitude are comparable was needed.

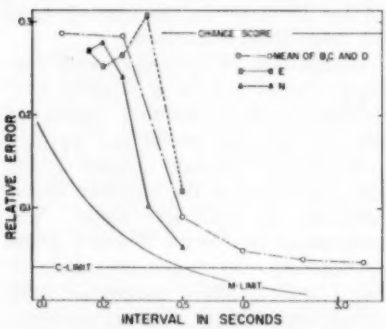

FIG. 3. Relative error (standard deviation) as a function of interval between flashes.

This requirement was met by using a brief flash at two luminance levels and by employing likewise two noise levels for the auditory click. The flash was 2 msec. long, so the auditory and visual signals did not differ radically in regard to duration. The use of two intensity levels for each of the signals permitted an assessment of the role of sensory magnitude. If in the range used a variation in physical magnitude over two logarithmic units had no appreciable effect, then presumably differences in the strengths of the visual and auditory signals could not be invoked to account for the differences in performances with the two senses.

Equipment. By simple modifications the relay circuit pulse in the Berkeley counter was made to trigger either the second single-cycle square-wave generator of a Roush electronic flash generator (Roush & Hamburger, 1948) or an amplifier leading to a loudspeaker, or both. The Roush device controlled duration and current to a Sylvania R1131C glow-modulator lamp. Two milliseconds was the duration, and current was set so that, for the conditions of observation, the flash in the crater of the lamp was at threshold when reduced about four logarithmic units. The lamp was viewed directly from a distance of about 1 m., either with no filter, or, for dim signals, with a Wratten 2.0 neutral density filter. For the sound it was necessary to use a low-pass filter (General Radio Type 830) in order to eliminate the basic frequency from the audio oscillator appearing constantly as part of the background in the relay circuit lead. Between the loudspeaker impedance-matching transformer and the 500-ohm output of the amplifier a Model 330 Hewlett-Packard attenuator was inserted. With 50 db. attenuation, the click in the speaker (University T-25) was barely audible. Data were collected with the attenution at 10 and again at 30 db. The speaker was approximately ½ m. distant from *S*, so the click arrived at his ear in less than 2 msec.

Subjects and Procedure. One *S* was an orchestra conductor and instrumentalist, and the other an Air Force officer highly skilled in sending telegraphic code. Reactions were by finger. The aim was to hit the lowest possible error indices, and each of the two *S*s was determined that his performance would set a record that could not be beaten. The competition between the two was friendly but extremely intense.

TABLE 3

CONSTANT ERRORS AND MEANS OF *SD*s (IN SECONDS)

Signal	Interval	ND		RE	
		Constant Error	*SD*	Constant Error	*SD*
Visual	0.167	0.012	0.045	−0.007	0.045
	0.200	−0.012	0.056	−0.003	0.051
	0.250	0.001	0.061	−0.009	0.066
	0.333	0.002	0.034	0.000	0.103
	0.50	0.010	0.030	0.019	0.059
Simultaneous Audio-Visual	0.50	−0.004	0.021	−0.003	0.018
Auditory	0.167	−0.021	0.023	0.009	0.026
	0.200	−0.018	0.024	−0.002	0.019
	0.250	−0.007	0.023	−0.003	0.019
	0.333	−0.015	0.022	0.003	0.018
	0.50	−0.006	0.019	−0.007	0.019

Five samples, each of ten trials, were collected at 6, 5, 4, 3, and 2 stimuli per second. The series was collected for each *S*, in a balanced design, using weak and strong auditory signals and weak and strong visual signals. For the rate of two per second, some additional data were collected with weak signals. Instead of five samples, there were ten. In addition, as a test to determine whether a combination of simultaneous weak auditory and visual signals might yield better scores than either alone, ten samples, also of ten trials each, were recorded with simultaneous presentation of the flash and click.

Results. Results with auditory signals differ from those with visual at each of the rates tested. Comparison of the data for simultaneous presentation of the two kinds of stimuli shows that, at least at these intensities, and at the two-per-second rate used in this comparison, performance is no better than with the auditory alone. Strength of signal likewise had no effect. Reactions to the weak light flash were similar to those for the brighter, and to the weak sound similar to those for the louder. Accordingly, in Table 3 the data for the two intensities have been pooled so that the constant error is based on 100 trials for all rates except two per second, and the standard deviation on ten samples of ten trials each. At two per second the number of trials was 300.

The auditory data are remarkable for the low variability. The data have already been displayed in Fig. 1 and 2. ND may have been slightly better at the slower tempos than at the fast, and RE did not make so low a score at the fastest rate as at the others. But in general the standard deviations were very low throughout the range tested. With visual signals, however, a quite different relationship between error and interval is manifest. The character of the relationship, and the differences in the records of the two *S*s are portrayed in Fig. 3 and 4. The log-log scales chosen for Fig. 4 render the comparison most simple and interesting. On such a display, *chance* becomes a straight line and the C limit likewise a straight line. The C function was postulated as the Weber fraction for reproducing longer time intervals, and, as in the preceding figures, is tentatively set at 0.036. Shown as circles on Fig. 4 are the means for the stand-

ard deviations of samples for *S*s in the preceding experiment. On this display these circles are seen to fall along the *chance* function, then to decline, and once again to rise for longer intervals. Triangles show the trend in ND's standard deviations. For the brief intervals they fall along the *chance* line, then for intervals greater than about $\frac{1}{4}$ sec. they improve. RE, on the other hand, shows nothing better than a random performance even at $\frac{1}{4}$-sec. interval. Somewhere beyond $\frac{1}{4}$ sec. some degree of synchronization becomes possible, and at $\frac{1}{2}$ sec. he has improved so that he is significantly better than chance.

If one extrapolates from these data on the basis of the performance of the three *S*s in the earlier experiment and on the assumption of the operation of the M and C limits, one would guess that ND would hold to his score as the interval was made somewhat longer, and then the error would increase for intervals 1 sec. and more in length. What RE might show in the range from $\frac{1}{2}$ sec. to 1 sec. is more in doubt, but presumably for intervals longer than 2 sec. his error again would grow with interval increase.

The data for ND and RE demonstrate that synchronization with one of a series of fast-paced auditory events is much better than for visual events. With visual stimuli, there is an upper limit encountered at rates as slow as three or four per second for some *S*s. The limiting rate depends upon the sensory channel. The upper auditory limit for ND and RE was not delineated, but presumably one would have appeared somewhere in the range from seven to ten stimuli per second. The limiting rate for synchronizing with visual stimuli varies from one *S* to another.

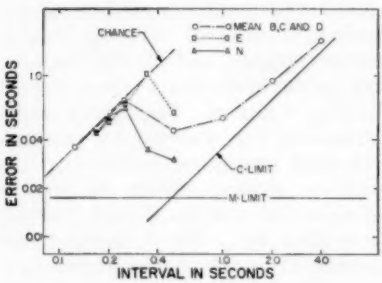

FIG. 4. Error (standard deviation) in seconds as a function of interval between flashes. Note log scale for both ordinate and abscissa.

SUMMARY AND DISCUSSION

In all the data on synchronization errors, variability tended to remain above the low figure reported for the variability in simple reactions to conspicuous visual flashes. The point can be made with confidence, particularly because one *S* participated in both kinds of experiments. To return to the reasoning in the introduction, the data on synchronization errors show the variability in the central triggering and motor execution independent of any variability in sensory processing but compounded instead with the variability in anticipatory mechanism. Either the latter variability is substantial, and different for an auditory-motor coordination than for visual-motor, or perhaps the entire line of reasoning is unsound. In any case, simple reactions to singly appearing strong stimuli by a well-trained, alert subject are less variable than are attempts to react in synchrony with one of a series of regularly repeated stimuli.

The radical improvement that ensues from using auditory rather than visual inputs brings up an interesting speculation. Perhaps possibilities for using the ear instead of the eye for some tracking tasks might be explored profitably. Noble, Fitts, and Warren (1955)

report difficulty in anticipating and compensating for simple repetitive motion of visual signals when rates became fast. They present an hypothesis to account for the failure. The hypothesis is interesting here for its emphasis upon central features rather than upon peripheral considerations of the second and eighth cranial nerve activity. The hypothesis included an assumption that *S* had a fixed sampling period for observing outputs, and since this period was independent of frequency, phasing errors (synchronization error) would increase with frequency. The demonstration here that synchronization error depends on sense modality suggests that perhaps Noble, Fitts, and Warren would have found higher rate limits if, for example, their tracking task had required *S* to compensate for shifts in the pitch of tones or in the locus of clicks, or in other variations that might be introduced in a continuing auditory input. If *S*s could track such signals at fast rates, Noble, Fitts, and Warren might be able to infer a shorter sampling period with auditory cues than with visual.

Perhaps the data here have some bearing upon musical performance. For example, the time error in synchronizing is fairly constant over the range most commonly used in music. But relative error depends on the tempo being, for example, at a much lower level for stimuli falling between 60 and 120 per minute than for faster tempos.

The simple theory presented in the introduction appears to describe the data. Some motor coordination effect fixes a limit to the accuracy with which one can synchronize. No evidence was found to show that this limit varies from voice to hand to finger or to toe, but, of course, the failure to find a difference is not conclusive concerning whether different motor units might impose different limits. Some sensory effect fixes the fastest rate at which events can be followed. As an interesting coincidence, the motor limit and the function showing the score for entirely random responses intersect somewhere in the vicinity of a rate of 10 to 15 stimuli per second—a rate not much faster than the 7 to 9 that appears to be the auditory limit for reporting number of stimuli. Finally, with long intervals, the error in synchronizing comes to depend upon skill in remembering and reproducing time intervals.

The point of intersection between the hypothetical function denoting the motor limit and that for the central or memory factor falls at approximately $\frac{1}{2}$ sec. In the notation used heretofore, the value for the interval at which the intersection occurs is M/C. According to the data, 0.018 sec. is a rough approximation for M and C is about 0.036, so M/C is about $\frac{1}{2}$ sec. One-half second is precisely the figure reported by Vince (1948) to be required for separating events in time so that rapid discrete simple reactions may be made. It appears from this study that whenever the interval between regularly spaced events exceeds $\frac{1}{2}$ sec., some memory factor enters into attempts to synchronize. These facts might be reinterpreted as meaning that $\frac{1}{2}$ sec. is the optimal interval to permit single stimuli to register in the central nervous system if one desires to achieve both a maximum effect from the stimulus and the shortest interval between that stimulus and a succeeding one without intrusion of extraneous factors. Regarded in this fashion, the results perhaps have some significance for conditioning theory. White and Schlosberg (1952) demonstrated that $\frac{1}{2}$-sec. interval is optimal for the delay between conditional and unconditional stimuli when a long-latency unconditional response is involved. Earlier studies had shown this to be the most favorable

interval for short-latency responses; the study by White and Schlosberg was important because it settled the question whether the significant temporal relationship was between the conditional stimulus and the unconditional response or between the conditional and unconditional stimuli. Evidently the stimulus-stimulus interval is the item of significance, and Vince's study and the one reported here indicate the optimal interval should be approximately ½ sec. It is.

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TOWARD EMPIRICAL BEHAVIOR LAWS
I. POSITIVE REINFORCEMENT [1]

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This account of reinforcement is based upon a generalization, not a theory. Few cases underly the generalization, but that which is generalized to are measurable properties of behavior.

If accurate, the present generalization will provide: first, an explanation of reinforcement; second, a criterion for evaluating the logical need for motivation constructs; and third, a possible basis for an empirical quantitative account of learning. This first paper, however, deals mainly with positive reinforcement. Learning, motivation, and the aversive case require independent treatment, though some reference to these topics will occur here.

The Rate Differential: A Necessary and Sufficient Condition for Reinforcement

The account is based on the assumption that the nature of reinforcement can be discerned by taking two responses (Rs) of the organism, arranging both of the possible contingencies between them, and noting what differentiates between the contingencies in which reinforcement does and does not occur.

A hypothetical example is provided by using a rat, the bar press, and the ingestion of pellets. If by reinforcement we mean, for the moment, the traditional increase in frequency of an R, the experiment will require two preliminary measures: (*a*) the rate of the bar press when the bar is available to the rat, which we will call the *independent rate* of bar pressing; and (*b*) the rate at which pellets are ingested when they are available to the rat, the independent rate of pellet ingestion.

Given the independent rates of both bar pressing and pellet ingestion, the experiment proceeds by arranging both contingencies: (*a*) the availability of a pellet contingent upon a bar press, and (*b*) the availability of the bar contingent upon the ingestion of a pellet. Consider that the former produces a rate of bar pressing greater than the independent rate, but that the bar contingent upon ingestion does not produce a rate of ingestion greater than that of the independent rate. What conclusions may be drawn as to the determinants of reinforcement?

Conclusions based upon the literature will include: need reduction, drive reduction, sensory stimulation, ingestive behavior per se, all combinations of the above. If, however, the conclusion is based solely upon the experimental outcome, it may read as follows: *Reinforcement results when an R of a lower independent rate coincides, within temporal limits, with the stimuli governing the occurrence of an R of a higher independent rate.*

A further consideration arises as a result of having measured the independent rates of both the bar press and ingestion. The rate at which pellets were ingested when contingent upon the bar press may approach the inde-

[1] This paper was prepared during the author's tenure as a USPHS postdoctoral research fellow. Part of this paper was read at the Midwestern Psychological Association, Detroit, May 1958, in a symposium on reinforcement. I am deeply indebted to my wife, Anne James Premack, for her assistance with both the formulation and clarification of this account.

pendent rate of pellet ingestion; the two rates could not be equal in all cases because of the bar press itself, but the former might approach the latter as the limiting case. Now, if the above were so and each bar press were followed by the ingestion of a pellet, the rate of the pellet-contingent bar pressing would tend to equal the independent rate of pellet ingestion. As it turns out, the proportionality is not that simple; the independent rate of the higher R does *not* limit the contingent rate of the lower-rate R, etc. Nonetheless, the following possibility is of heuristic value: In the idealized case, the dependent or contingent or acquired rate of the lower-rate R tends to equal the independent rate of the higher-rate R.

Are these the only possible conclusions? They may be if only the one case is considered. But if we assign as great a weight to the negative as to the positive finding, and take an inductive leap, we may conclude as follows: *Any response A will reinforce any other response B, if and only if the independent rate of A is greater than that of B.*

This is the induction that will be examined here; not proved, the evidence to be presented is altogether insufficient, but examined for the definition of terms, implications, and, briefly, for quantification possibilities.

TEST METHODS

A test of this account concerns three main questions. First, is a rate differential a sufficient condition for reinforcement? Second, will the effectiveness of the differential vary as different variables constitute the rates of the Rs involved? Third, will the lower-rate R attain exactly the independent rate of the contingent higher-rate R? The latter is not incorporated in the quantitative version, but is retained here, so as to consider performance factors that may disturb equality between the two Rs.

Tests of these questions require independent measures of both of the Rs involved, but few experiments provide this information. In runway studies there is no measure of the independent rate of the "runway R," no simple way of obtaining such a measure, and typically no measure of the R that terminates the run. Though the Skinner box provides in principle for measures of both Rs, in practice we have no measure of the higher-rate R, viz., ingestion, licking, or, more recently, rising up and sniffing the light source. Methods suited to the present questions are described below. Only the first is adequate, however, and after both are described, advantages of the one will be noted.

Rs Ranked Along a Rate Continuum

If the independent rates of several of an organism's Rs are determined in advance, the Rs can be ranked in terms of rate, and the account tested by arranging all possible contingencies between the ranked Rs. Let A, B, and C represent any three Rs, with independent rates in the order stated. It follows from the account that: A will reinforce both B and C, C will reinforce neither A nor B, and B will reinforce C but not A.

Support for the view of reinforcement as an absolute property is given by both A and C. Since A is and C is not a reinforcer, they exemplify the proposition that some stimuli are and some are not reinforcers—in a broader sense, that species are characterized by a set of stimuli which is and a set which is not reinforcing. The conclusion that reinforcement cannot be explained on the behavior level typically follows from this view, i.e., follows from, first, assigning reinforcement to

a set of stimuli, and then noting that the set cannot be physically characterized.

The reinforcement properties of B suggest, however, that the absolute view is based upon failing to consider the rate of the would-be reinforcing R relative to the rate of the to-be-reinforced R. B shows this well since, if the account is accurate, B both is and is not a reinforcer. The reinforcement properties of B suggest, therefore, that "Is this stimulus a reinforcer?" requires the further question "With respect to what Rs?" (In the present terms, if the rate of the R governed by the stimulus in question is greater than that of the to-be-reinforced R, the stimulus can be used as a reinforcer.) But tests that use only one "instrumental" R or that deal solely with rat, ingestion, and usual laboratory parameters are unlikely to show the relativity; this combination assures that the independent rate of the ingestive R will exceed that of the "instrumental" R. Other combinations of species, Rs, and parameters demonstrate the relativity; one which permits reinforcing ingestion is shown in a later section.

The data to be reported here, however, are intended largely as a concrete example; they concern one subject and realize only part of the paradigm. The subject is a Cebus monkey, a species Klüver (1933) has described as being especially manipulative. The Rs ranked in terms of rate are all manipulation Rs; they were used to show the reinforcement of one "instrumental" R by another, i.e., to show that what makes an R "instrumental" is a rate less than that of the contingent R.

An apparatus has been devised which permits giving the subject a number of different manipulanda, either singly or in pairs. When used to determine the independent rate, the different manipulanda are given to the subject, one at a time, under a standard test condition, and with no restrictions upon responding. When the manipulanda are given in pairs, either one can be locked and its operation made contingent upon the prior operation of the other and free manipulandum of the pair. Operation of the free member releases the locked member, and operation of the previously locked member restores its own lock. In this way a consistent schedule is arranged between operation of the free member and release of the locked member. Only one release of the locked member is provided by any number of operations of the free member.

A panel, which holds any one or any pair of manipulanda, is bolted to a port in the monkey's home cage, and all testing is conducted there. Testing is in home cage so as to approximate an environment in which unmeasured Rs are low and stable. The need for a low, asymptotic level of "competing" Rs is emphasized by this account; according to it, a competing R of an independent rate greater than that of the measured R can, by uncontrolled contingencies, reinforce the measured R.

The three Rs used so far are: lever pressing, operation of a horizontally hinged door, and the bin R in which the animal pushes back a light door mounted behind a hole and contacts an empty bin. The independent rates of these Rs were determined by giving the subject the appropriate manipulandum on five to ten 90-minute sessions. The subject was tested daily, but each item was given equally often daily, on alternate days and every third day, so that the mean intertest interval per item was about 48 hours. The long interval was used to maintain R-frequency per item at near maximum from test to test. The independent rate of manipulation Rs varies with several parameters, which will be noted

later, but may be kept relatively constant by the usual controls and by avoiding short intertest intervals which result in a cumulative decrement. For the parameters used, the mean frequencies were about 20 for the bin, 50 for the lever, and 100 for the door.

The tests described below followed, by 24 hours, the determination of the independent rates. Six of each kind were given daily in the order described, except for extinction, where only four were run. The tests concern only the door and lever. Because of presenting the same pair of manipulanda at only 24-hour intervals, an over-all decrement occurred. The reinforcement effect occurred despite the decrement.

First, when the subject was given the two manipulanda together, with no contingency between them, so that both the door and lever were free, the lower-rate R appeared to occur at less than its independent rate, while the higher R occurred at about its independent rate. For the six tests, the door averaged about 90, the lever about 36. Whether this kind of situation suppresses the lower-rate R cannot be evaluated because of the decrement associated with an intertest interval less than the one used to determine the independent rates. In the present series, however, this control condition served only to determine if presenting together previously unpaired manipulanda would produce an increment in the lower-rate R. That no increment occurred is the outcome important for the test series.

Second, the lower-rate R was made contingent upon the higher-rate R by now making operation of the lever contingent upon the prior operation of the door. The door averaged about 80, the lever only about 22. Because the higher-rate R tended to occur first and relatively often, the lower-rate manipulandum was actually free both from the outset, and for most, of the test period. However, each lever press left the lever locked. Consequently, the subject could not respond to the lower-rate manipulandum in its customary "bursts," but could make closely spaced lever presses only by alternating higher- with lower-rate Rs. The alternation did not occur, however. Instead, after making a lower-rate R, the subject made varying numbers of higher-rate Rs, after varying intervals, and then returned to the lower-rate R after varying intervals. *Mainly, this lack of alternation between free and locked members demonstrates the failure of a lower-rate R to exert a controlling effect upon a higher-rate R;* it contrasts with the alternation which occurs when the rate differential is in the opposite direction, viz., from low to high. Finally, did the lower-rate R fail to reinforce the higher-rate R because the former did not follow the higher-rate R either sufficiently often or closely? This possibility cannot be ruled out, and finer tests of this point are needed. An important consideration for such tests, however, is that reinforcement is witnessed not by occurrence of an R, but by a rate of occurrence greater than the independent rate.

Third, the rate differential was arranged from low to high by making the higher-rate door R contingent upon the lower-rate lever press. The lever press attained a mean frequency of about 120, which contrasts both with its original independent frequency (about 50) and with that of the door R (about 100). Thus the lower-rate R was not only increased but exceeded the independent frequency of the higher-rate R. On the first two tests the higher-rate R was notably reduced, though it attained its original independent frequency on the last two of the six tests. Three factors are notable

here. (*a*) Because of its contingent status, the higher-rate R could not occur in its usual "bursts"; this may account for the reduced rate on the early tests, and an accommodation to this factor, for the steady increase in the higher-rate R that took place across the six tests. (*b*) As the free R, the lever press could and to some extent did occur in "bursts," which may account partly for the fact that on all tests the number of lower-rate Rs exceeded the number of higher-rate Rs. An average of about 80% of individual lever presses were followed by a door R; this represents the alternation between the two Rs. The percentage did not increase across tests, though there were essentially no "bursts" of lever presses in any test not directly followed by a door R. Hurwitz (1958) has reported a case for rats and food-contingent bar pressing where, at an intermediate stage of training, bar presses exceeded pellets ingested, though the two Rs alternated with further training. The ultimate performance proportionality between the two Rs may be affected by the absolute rate of the higher R or by the difference between the rates of the two Rs. (*c*) Responding increased across this series of tests, in contrast to both test conditions above.

Fourth, extinction was run by removing the door from the panel, closing the port which the door had occupied with a blank, and giving the subject only the lever. This is the situation in which the independent rate was originally determined. As an extinction condition it is blunt: the stimuli governing the higher-rate R are grossly absent. Nonetheless, the subject pressed the lever at an elevated rate (78 and 56) on the first two sessions and then dropped progressively on the last two sessions to a level below the original independent rate.

While these data suggest that a rate differential is a sufficient condition for reinforcement, they have been reported as the most concrete means of describing a test method. Comparable tests are being extended to the greater number of Cebus now available.

Measuring Independent Rate in the Context of the Test

In contrast to the method described, where the independent rates are determined in *advance* of the contingency tests, a second method consists in measuring the independent rates in the context of the test. For example, the runway or choice-point can be combined with an apparatus that permits measuring the rate of the Rs that occur in the end boxes. Runway speed can then be examined for its relation to rate of end-box Rs, or choice-behavior for its relation to the difference between the rates of the Rs in the two end boxes. Since, however, this account is stated in terms of rate, it cannot treat either runway speed or percent turns. But even at the level of suggestion, data obtained with the second method may be misleading in their interpretation for this account.

When rates are determined during rather than before the contingency tests, the resulting data will relate *number* of higher-rate Rs to the dependent variable, e.g., number of end-box Rs to speed of the run. If we designate the "runway R" as A, and Rs that terminate runs for groups tested with different end-box items as B and C, the tests will contrast, say, $A \rightarrow BB$ with $A \rightarrow CCCCC$. In the first method, however, not more than one higher-rate R need follow a lower-rate R. In the manipulation case, for example, only one door R followed any lever press. Consequently, the contrast may be between $A \rightarrow B$ and $A \rightarrow C$, where A is a common lower-

rate R, and B and C are higher-rate Rs with independent rates determined in advance of the contingency tests. The first method emphasizes, therefore, as the second does not, that in order to produce an increment in the lower-rate R, only *one* higher-rate R need follow the lower-rate R.

In the light of this emphasis, the first method suggests further that one contingency, rather than repeated trials, between Rs of different independent rates will produce an increment in the lower-rate R. That is, if $A \rightarrow B + A \rightarrow B + A \rightarrow B$, etc., produces an increment in A, so will $A \rightarrow B$. In the manipulation example above, this suggests that *one* contingency between the lever press and door R will produce an increment in the lever press, the increment to be evaluated by comparing an extinction measure with the previously determined independent rate. Except as discontinuities are considered either at the level of number of contingencies or interval between contingencies, one contingency between one lower- and one higher-rate R would be considered to produce an increment in the lower-rate R.

Especially for quantification possibilities are these important considerations. If single contingencies are effective, then the differences between *mean* rates, which we are using here, can *not* be made the basis of reinforcement. That is, since the single R cannot have a mean value, a function relating changes in the lower-rate R to some relation between lower- and higher-rate Rs must employ R values other than mean rate. Considerations of this kind, however, concern learning rather than performance. For the data treated here mean rate will suffice; the measure may be viewed as an approximation of whatever R value may serve ultimately to permit the kind of function that is being sought.

REINFORCEMENT OF CONSUMMATORY RS

It follows from this account that consummatory Rs are reinforcible, provided that a condition can be found in which the organism's rate of, say, ingestion is less than the rate at which it performs some nonconsummatory R. This rate relation, however, is the reverse of the one which obtains in the usual laboratory test. There the "instrumental" R is a noningestive R, the contingent R a consummatory R, and the rate relations such that the latter is substantially higher in independent rate than the former. The food deprivation, which is part of the usual test, assures a high independent rate of ingestion. Though it may also increase the independent rate of the "instrumental" R, the increment given the latter will not offset the advantage of the ingestive R, since particularly the maximum independent rate of ingestion will exceed that of the "instrumental" R. To use ingestion as the "instrumental" R, however, requires that it now have an independent rate less than that of the contingent and would-be reinforcing R. The ease of establishing this condition appears to vary with the species.

In the rat, and perhaps the rodents generally, the difficulty begins with the fact that ad lib. maintenance does not lead to a rate of ingestion which is less than the independent rate of the common and engineerable nonconsummatory Rs. The momentary rate of the rat's ad lib. eating session is unusually constant (Baker, 1952), and this constant tends to be higher than the maximum independent rate of, say, the bar or light-contingent bar press, at least for those values of food, bar, and light intensity which we have tried. While there may be a low-rate food and high-rate light intensity which together will yield a reversal of the customary rate

relations between ingestive and noningestive Rs, we have not found the values.

Moreover, reducing the ad lib. eating constant by a deprivation technique does not facilitate the reinforcement of eating. By first depriving the rat of food, a low eating rate can be obtained; following deprivation the rat does not eat at a constant rate, but under some circumstances begins at a value greater than the ad lib. constant and terminates at a very low value (Baker, 1952). However, when the terminal eating rate is low, the independent rates of the other Rs may be equally low. And if satiation effects are broad, reducing the rate of all Rs, little reinforcement of any kind will be possible.

Other techniques may work. For example, the wheel turn which, in the rat, has a substantially higher independent rate than the bar press, and which Kagan and Berkun (1954) have shown to reinforce the bar press, may serve to reinforce ingestion. But the difficulty of finding stimulus pairs and parameters which will provide the desired rate relations in the rat comments merely on a species peculiarity of the rat.

Measures on a Cebus monkey indicate that parameters can be found under which the monkey operates some manipulanda at a rate greater than that at which it ingests most foods. Beyond the Cebus, however, the child may be the ideal subject. For certain age levels and socioeconomic classes, the desired rate relations appear to obtain within the parameters of the child's daily life. The study described below shows that a reversal of the usual laboratory rate relations between eating and noneating Rs can be obtained with the child and, that when it is, eating is reinforcible.

A pinball machine (PBM), rewired for continuous operation, and a candy dispenser, the two placed side by side, comprised the experimental arrangement. A PBM was used instead of the simpler devices in use with the monkeys, since the present purpose was less to analyze manipulation than to obtain as high a manipulation rate as possible. Candy consisted of constant-size chocolate bits, delivered one at a time by a conveyer belt into a dish each time the child ate the piece in the dish. Thirty-three children, the entire first-grade class of a public school, served as subjects. Their average age was 6.7 years.

Each child was tested twice, the first serving to determine the subject's relative R frequency to the candy and the PBM, and the second as the test of the hypothesis. Both tests lasted 15 minutes and used the same materials; the second was given three to four days after the first.

On the first test, both the candy and PBM were unrestrictedly available. The child was led to a position midway between the two devices and told, "We have two games here; you can play both of them as much as you like." After demonstrating both devices, the experimenter said, "I'll be back here sitting down," and then retired behind a one-way viewing screen. Sixty-one per cent of the children made more PBM responses than they ate pieces of candy. In Table 1, they comprise the larger group labeled "manipulators"; those labeled "eaters" represent the 39% who ate more pieces of candy than they made PBM responses (three ties which occurred were scored as "eaters").

On the second test, the availability of candy and the PBM were made subject to either of two contingency relations, E-M or M-E. For E-M, each operation of the PBM was contingent upon the prior ingestion of a piece of candy, whereas for M-E, each piece of candy was contingent upon the prior

operation of the PBM. Both the "manipulators" and the "eaters" were randomly divided, and half of each main group tested under E-M and half under M-E. For "manipulators" E-M was the experimental condition and M-E the control; the reverse held for the "eaters." What characterizes both experimental conditions is that the higher-rate R is contingent upon the lower-rate R ("manipulators" must eat to manipulate; "eaters" must manipulate to eat). Control conditions make the higher-rate R freely available, as in Test 1, and thus provide a measure of changes in the lower-rate R which may occur independent of the rate-differential contingency.

TABLE 1

INCREASE IN LOWER RATE RESPONSE FROM FIRST TO SECOND TEST

Manipulators	
E-M (Exp.)	M-E (Control)
Increment in number of pieces of candy eaten per subject	
16	0
16	4
19	19
22	0
14	5
14	10
28	0
19	0
26	7
81	a
$\bar{X}$ 25.5	$\bar{X}$ 5
Mdn. 19	Mdn. 4

Eaters	
M-E (Exp.)	E-M (Control)
Increment in number of PBM responses per subject	
10	5
8	0
7	0
1	0
16	7
9	0
16	
$\bar{X}$ 9.4	$\bar{X}$ 2
Mdn. 9.0	Mdn. 0

[a] Child absent on Test 2.

Like the magazine-trained rat that responds to the inoperative magazine rather than pressing the bar, "manipulators" in the experimental condition "fiddled" with the inoperative PBM, ignoring the candy, while "eaters" stood by the empty dish, ignoring the PBM. Consequently, because of the time-limited session, instructions were used to establish the first contingency (defined as a PBM response followed by the ingestion of candy, or vice versa, regardless of the time between the two responses). If three minutes elapsed without a response, the experimenter said, "Remember, there are two games." If this failed, he then said, "I wonder what would happen if you ate a piece of candy? Played the PBM?" according to whichever was appropriate. Once a contingency occurred, nothing further was said.

The results are shown in Table 1 in terms of the increase in the number of lower-rate Rs from the first to the second test. For "manipulators" this is the increase in number of pieces of candy eaten; for "eaters," increase in number of PBM responses. As may be seen in Table 1, control-condition increments are small compared with those for the experimental condition, and the mean differences within both main groups are significant at less than the 1% level of confidence. In both cases, a rate-differential contingency increased the frequency of the lower-rate R: While candy reinforced manipulation for the "eaters," the PBM reinforced eating for the "manipulators."

More elegant demonstrations with nonverbal organisms are needed, but the above results suggest that the uniqueness of consummatory Rs does not consist in their unreinforcibility.

They may be distinctive in the high rates which they attain relative to the other Rs, though the rate relations possible for the different Rs appear to vary with the species. For example, Lorenz (1957, pp. 129–175) has noted that stalking in certain predators commonly attains, in present terms, an independent rate greater than that of ingestion. As a survival mechanism, perhaps there may be, however, a number of parameters in all species under which the independent rate of ingestion exceeds that of the other Rs.

Finally, the above study is of interest for its suggestions concerning the relativity of reinforcement. That species are *not* characterized by a specific set of reinforcing stimuli, and that this mistaken absolute view has resulted from failing to consider the rate of the would-be reinforcing R *relative* to that of the to-be-reinforced R, are main suggestions of the study. Indeed, that reinforcement is not only a relative property but, in some instances, a reversible one is also indicated. For example, there would seem little doubt but that with sufficient food deprivation "manipulators" would become "eaters" and, consequently, that the R which had been "instrumental" could be made reinforcing, and vice versa. A comprehensive treatment of both the relativity and reversibility is reserved for a later paper. Here the main point is simply this: Any stimulus to which the species responds can be used as a reinforcer, provided only that the rate of the R governed by the stimulus is greater than that of some other R.

"DRIVE"

Effect of the Intertest Interval

While the broad effects of food deprivation are apparently unique, the effect of the interval between feeding sessions *specifically* upon ingestion may represent a general function, one holding for the independent rate of any movement and the interval between occurrences of the movement.

For example, Butler (1957) has shown visual-contingent responding in the rhesus monkey to increase with deprivation for visual stimuli. Hill (1956) has reported wheel turning in the rat to increase with the confinement interval. For independent groups of rats tested at intervals of 12, 24, and 48 hours, Premack, Collier, and Roberts (1957) found both the bar press and light-contingent bar press to be increasing functions of the intertest interval. For the same group of rats rotated through five intertest intervals ranging from 3 to 48 hours, and tested eight consecutive times at each interval, Premack (1958) found the light-contingent bar press to be an increasing function of the interval. Finally, Premack and Bahwell (in press) found lever pressing in a Cebus monkey to be a generally increasing function of deprivation for the lever. Given the same lever on 252 half-hour sessions, an equal number of sessions at about 15-, 39-, and 65-hour intervals, the monkey responded 4,109 times; significantly most often at the largest interval; and showed no decline across the about 5-month test period. Continued examination of species movement may reveal differences in temporal parameters, but a common increasing function for independent rate of all movement and deprivation for the stimuli upon which the movement depends.

As to the general effects of food deprivation, some parallel may possibly be found in depriving the organism of *any* behavior which, like ingestion, has a high independent rate and is recurrent throughout the organism's life. For a nonconsummatory R, the wheel turn tends to have these charac-

teristics in the rat. Slonaker (1926) has reported that rats turn a continuously available wheel at a substantial rate during about two-thirds of their life. Moreover, the decrement in the wheel turn reported to occur across repeated tests (Hill, 1956) does *not* distinguish the wheel turn from ingestion. We have found rats to ingest significantly more of a new food on the first than on succeeding days; when shifted from ad lib. lab food to Gaines dog meal, rats ate a mean of 19.98 grams the first day and only 14.19 grams by Day 14 ($p < .01$, $F = 2.41$, df 13/143); across days decline has been found also for Noyes pellets. On the basis of these parallels, Premack and Premack (1958) studied ad lib. food consumption as a function of deprivation for a continuously available activity wheel. When deprived of the wheel, rats ate significantly more than they had when the wheel was available and than a control maintained without the wheel. In two replications, grams intake attained a maximum on about the third post-wheel deprivation day, and intake did not return to baseline for about 14 days.

What seems most likely to distinguish food deprivation from deprivation for stimuli governing noningestive Rs are the different relations within the stimulus classes. Let A, B, C, and D subsume the members of the food class. Though no data can be found on this point, it seems probable that organisms deprived of the class, and tested on, say, A, would ingest more of A than a control maintained on B, C, and D, and tested on A. In the case of nonfood stimuli, however, depriving for increasing amounts of the stimulus class appears to *reduce* the over-all response level. Ochocki and Premack (1958) maintained one group of rats in the colony, another group in light-tight, sound-treated icebox hulls, and tested subgroups of both main groups on the light-contingent bar press at intervals of 3, 12, and 48 hours. While responding was an increasing function of the intertest interval for both main groups, frequency was significantly lower at all intervals for the stimulus deprived group.

"Drive"

Whereas in the Hull-Spence system, hours of food deprivation is related to D, and D ultimately to performance, in this account hours of food deprivation is first examined for its effect upon the independent rate of ingestion. Subsequently, the independent rate of ingestion is examined for its effect upon lower-rate Rs that lead to ingestion. Though tradition has set the ingestive case off, by calling it "drive" or "motivation," in this account the effect of the ingestive contingency does not differ in modus operandi from that of *any* higher-rate R—manipulative, locomotive, or sensory—upon the paired lower-rate R.

Of the paradigms which can be used to test the reinforcement generalization, the one most relevant to the usual "drive" study is the following: The *same* higher-rate R, when at different values of independent rate, is made contingent upon a common lower-rate R. Thus, in the customary "drive" study the higher-rate R for all groups is ingestion, and the differences in hours of food deprivation represent possible differences in the independent rates of ingestion for the several groups. This paradigm contrasts with one in which *different* higher-rate Rs are made contingent upon a common lower-rate R, but the prediction made by the reinforcement generalization is the same for both paradigms, viz., the increment in the lower-rate R will be greater, the greater the independent rate of the contingent higher-rate R.

Because the intervening variable approach has dominated the field, little data relevant to this account can be found. The literature shows two separate approaches: (*a*) determinants of the independent rate of ingestion, and (*b*) effect of hours of food deprivation upon food-contingent Rs. Tests of this account require that the two approaches be united in the same study.

Consider as a typical "drive" study one in which several groups are differentiated in terms of hours of food deprivation and tested on the same food-contingent, lower-rate R. To convert this study into a test of this account requires two measures, both of which are omitted by the intervening variable approach. First, we require the effect of hours of food deprivation upon the independent rate of ingestion, and second, the effect of hours of food deprivation upon the independent rate of the R that is to be used as the "instrumental" R. Food deprivation may affect the rate of the "instrumental" R *before* it has been made food-contingent in the study, and the effect may be different for the several groups. Moreover, for certain deprivation procedures, hours of food deprivation may affect differently the "instrumental" and ingestive Rs.

A recent study by Birch, Burnstein, and Clark (1958), coupled with a less recent one by Bousfield and Elliott (1934), approximates the methodology of measuring, first, the effect of the independent variable upon ingestion and, second, the effect of the ingestive contingency upon the lower-rate R. Together they also provide a bit of information as to whether the effect of hours of food deprivation is the same for the "instrumental" and ingestive Rs.

In both studies essentially the same independent variable was used. Rats were first maintained for protracted periods on a fixed deprivation schedule and then tested at varying hours after their last feeding. The studies differ in terms of their dependent variables. In what amounts to an extinction measure, Birch et al. found that number of approaches to the empty feeding device was greatest at the previously scheduled feeding time, less for times both greater and less than the scheduled feeding time. Bousfield and Elliott considered the effect of the same variable upon ingestion itself. They found the rate of ingestion, as well as grams intake, to be greatest for the group tested at the scheduled feeding time, less for groups tested at all other times. Thus, the relation to hours of food deprivation was the same, both for the extinction measure of the food-contingent R and the independent rate of ingestion. And in neither case was this the monotonic increasing relation that has been shown, with other deprivation procedures, to hold for grams intake and hours of food deprivation (Lawrence & Mason, 1955).

Birch et al. next tested runway speed as a function of the same variable. On the first trial, *before* a run had led to ingestion, speed and hours of food deprivation were not significantly related, though there was an indication of increased speed with greater deprivation. However, on the second trial, *after* a run had led to ingestion, runway speed was greatest for the group tested at the scheduled feeding time, less for groups tested at all other times. Thus, while comparison of the first-trial results with those by Bousfield and Elliott suggests that, for this deprivation procedure, hours of food deprivation may affect differently the ingestive and "instrumental" Rs, once the "instrumental" R had led to ingestion it was related to hours of food deprivation in the same way as was the independent rate of ingestion. Taken in sum, these results suggest that the independent

rate of ingestion is itself the direct determinant of changes in ingestion-contingent lower-rate Rs, in contrast to hours of food deprivation, which acts merely to affect the independent rate of ingestion, as well as possibly the independent rate of the "instrumental" R. Moreover, when compared with the manipulation example, they suggest that the effect of a higher-rate ingestive R upon the paired lower-rate R does not differ in modus operandi from that of a higher-rate manipulation R upon the paired lower-rate R.

Birch et al. placed only two pellets in the runway end box; if one had been used, we would predict the same group differences. The assumption here, as noted earlier, is that an increment in the lower-rate R, that is some function of the relation between the mean rates of the lower and higher Rs, can be produced though only one higher R follows the lower R. An increment occurred in the lever press, for example, though only one door R followed any lever press. Mean rate is being used as an approximation, however. If contingency changes in the lower-rate R are to be calculated directly from pre-contingency measures of both lower- and higher-rate Rs, it is already evident that R values other than mean rate will be required.

The broad effects of both food deprivation and satiation are unique, but these distinctions notwithstanding, the ingestive case is subsumed by the reinforcement generalization on the following grounds. First, a rate produced by food deprivation does not differ in its reinforcement effect from a rate produced by any other operation. Second, the modus operandi of the ingestive contingency is the same as that of any higher-rate R. Third, the shape of the function for increments in ingestion-contingent lower-rate Rs and hours of food deprivation is directly predictable from the function for the independent rate of ingestion and hours of food deprivation. If further study bears these considerations out, then for the inferences of the intervening variable approach there may be substituted measurement of the independent rates of the lower- and higher-rate Rs.

COMMENSURABILITY OF BEHAVIOR UNITS

In the tests of independent rate described earlier, the subject was simply given test items under a condition that was the same for all items. No restrictions were placed upon the items, the subject determined its own units of responding, and the records, as measured, consisted of a succession of manipulanda operations, ingestions of food units, and, in some unreported work, succession of wheel revolutions. No criterion for dividing these behavior segments was provided. In effect, each segment of unrestricted responding was divided by the anthropomorphic unit, e.g., "lever press," "pellet ingested," etc. Though, at this stage, the main justification for these R units is that the comparisons "worked," in retrospect it is possible to make explicit the assumptions underlying the choice of units and thus to provide a formal criterion for selecting the R unit by which to count the independent rate of any segment of unrestricted responding.

The assumption which is here applied to all behavior segments generated by unrestricted test items is that each segment contains what might be called a smallest possible unit (spu). *The* spu *is defined as that unit which gives the same amount of responding as is given by free responding, when in fact stimulus restrictions force the organism to respond by* spu.

In the ingestive case, spu would seem to amount to the intact chain,

i.e., to a combination of seizes, bites, chews, and swallows which is recurrent throughout the unrestricted segment, though make-up of the combination may vary with the organism, as well as with degree of food deprivation, size of pellet, consistency, etc. To treat the intact ingestive chain as the spu amounts to considering that: if stimulus restrictions forced the organism to respond by discrete chains, in equal periods of stimulus availability, it would ingest essentially as many pellets as when pellets were free and it responded by its characteristic multiple of intact chains. Tests of this assumption can be made by more complex procedures than were used here; they would involve variously restricting both the number of food units available at any one time and the intervals between their availability. However, the contingency situation itself amounts in part to such a test, since there the occurrence of the lower-rate R imposes intervals between multiples of the organism's free responding units. Consequently, if the single intact chain were made the contingency unit, and the asymptotic amount of pellets ingested in that situation tended to equal the amount ingested in tests of unrestricted responding, evidence would exist for treating the intact chain as the spu.

To perform the above test requires a knowledge of the number of intact chains that occur per pellet or multiple of pellets. Since pellets vary as to size, in order to count the unrestricted ingestive segment by intact chains the pellets would have first to be calibrated in terms of the organism's R units. The independent rate for the segment of unrestricted ingestion would then amount to: number of pellets ingested per unit time by number of chains per pellet or multiple of pellets. Though calibration will make some occasion for the direct observation of behavior unavoidable, calibration is unavoidable; if the experimenter's stimulus-effect measurement unit were simply equated with the R unit, the independent rate of the segment could be made to vary with the choice of food units.

Seizing, biting, chewing, etc., cannot be used to count the independent rate of the unrestricted ingestive segment, except as the correlation between certain of these units and the intact chain is known. In the context of unrestricted ingestion, it may be expected that the smaller units do not occur at their independent rate. Seizing may be affected by biting, biting by chewing, etc., though to determine which reinforce which others would require testing various combinations of them in isolation of the rest, insofar as that is possible. When tested in isolation, each of the smaller units would be expected to stabilize at some value of independent rate, but in each case at values less than that of the intact chain.

In the context of unrestricted ingestion, certain of the smaller units appear to occur multiply within the chain, and thus at a rate greater than that of the intact chain. The within-chain arrangement may be such as to schedule ratios of certain of the smaller units with respect to others; for example, a number of chews may antecede a swallow. But that the within-chain rate of all such units is dependent, not independent, could be shown, presumably, either by testing them in isolation or, what would amount to the same thing, by making any one of them the contingency unit. As contingency units, seizing or biting or chewing, etc., would be expected to fall short of their within-chain rates. And, in general, when the rate of the contingency unit does not approach the rate at which the same unit occurred when the unit was a part of the segment of unre-

stricted responding, there is evidence that the segment was not counted by the spu, but by some unit of dependent rate.

The manipulation case reported suggests that single operations of the manipulanda may comprise the spu for segments of unrestricted manipulation. Both rats and monkeys appear to manipulate in "bursts," i.e., by multiples of lever presses, etc. Nonetheless, when the Cebus was given the door in contingent status, and thus restricted to discrete operations of the door, the immediate and substantial reduction in the door Rs was transient. By the fifth contingency test, the door R had reacquired its original rate, though it was then limited to discrete occurrences in contrast to the multiples characteristic of unrestricted manipulation.

An essential parallel between intact ingestion and manipulation chains may possibly be shown as follows: for manipulanda which yield different independent rates of operation, *contacts* to the same inoperable manipulanda may vary little and in all cases stabilize at independent rates substantially less than those for operations. Indeed, in the Cebus the generally high manipulation rate may make it possible to schedule, say, lever presses with respect to lever contacts. Though species may adapt to disrupted multiples of intact chains, the adaptability cannot be thoroughgoing. Instead. for repeated tests at the same intertest intervals, different movements of the species may be expected to stabilize at different independent rates. Work of this kind would further the brilliant, pioneer investigations by Schiller (1952) concerning species-specific movements in the chimp, and the relevance of these movements to what has been called insight.

In locomotion a blind, empirical approach is necessitated by the relative absence of anthropomorphic units coupled with the difficulty of observation. With the rat and the activity wheel the spu may possibly be found by testing across a series of decreasing stimulus restrictions. Starting with a small fraction of a revolution, the distance the wheel is made available on any one operation may be gradually increased, until a per operation distance is found which, in equal periods of wheel availability, yields a total distance of use equal to that for the unrestricted wheel. If such a unit exists, then the independent rate of the segment for unrestricted wheel turning would amount to: number of revolutions per unit time by number of spu's per revolution or multiples of revolutions. This technique would accommodate differences in wheel diameters, and would not require topographical calibration of the measurement unit.

A different and more general approach to the problem of determining the independent rate for behavior segments lacking in anthropomorphic units has been suggested by MacCorquodale.[2] In brief, the method consists in first ranking Rs that are easily counted. Provided the reinforcement generalization holds across the group of ranked Rs, their rate continuum is then used to locate the independent rate of arbitrary units taken from behavior segments that are difficult to count.

Finally, that rate is a property common to disparate movements and that a method may possibly be found for assigning but one value of independent rate to any segment of unrestricted responding are themselves of little consequence. Advantages depend upon using the common property as the basis for a function, for only then do the disparate movements become commen-

[2] K. MacCorquodale. Personal communication, November 1958.

surable in terms of their values for the common property.

The function that is entailed by the reinforcement generalization is nonspecific, though within the limits of that function there is a definite commensurability between the different Rs. Because the generalization treats a rate differential as a sufficient condition for reinforcement, ranking the Rs of an organism in terms of their independent rates should permit predicting which Rs will reinforce which others. Only the R with the highest independent rate should be a universal reinforcer, only the lowest R fail to reinforce any other R, while those intermediate on the continuum should reinforce all those below themselves and be reinforced in turn by all those above. Moreover, all Rs of like independent rate would be equal; they would reinforce the same lower-rate Rs and be reinforced in turn by a common group of higher-rate Rs. The function is nonspecific, however, in that it does not permit specifying the dependent rate that will be attained by the lower-rate R. And what is being sought is the function that will permit calculating dependent rate from measures of the independent rates of the two Rs involved in any instance of reinforcement.

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A FUNCTIONAL ANALYSIS OF AUTHORITY[1]

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An important segment of social interaction that requires systematic analysis is the behavioral control of one person over another: in other words, authority. The purpose of this paper is to analyze this type of interaction for the dyad, showing of what variables it is a function.

Authority, as defined below, is seen as a special case of verbal behavior as analyzed by Skinner (1957), and is consonant with his definition of the "mand." Thus, the analysis of authority will make fundamental use of the concept of the reciprocal reinforcement of behavior. The general aim is to carry through an analysis of the dyadic situation, and simple extensions of it, that specifies the conditions that are relevant to the occurrence of "authority behavior" and the variables of which such behavior is a function.

We begin with a definition of authority. A basic paradigm of an authority sequence will then be given and the variables of which such an authority sequence is a function will be discussed in detail. Finally, functional relationships between authority sequences will be analyzed.

Definition of Authority

We define authority as follows: Person A has authority over Person B, in a given situation, when a response of A, under the control of deprivation or aversive stimulation and specifying its own reinforcement, is reinforced by B.

This definition implies that authority is a social relation under the dual or reciprocal control of both A and B. It is social in the sense that it requires behavior on the part of both A and B and that the behavior of A constitutes a stimulus for B and vice versa. For the relation to be maintained, B's behavior must be reinforcing for A and A's behavior must be reinforcing for B. As will be discussed later, the controlling relation of A over B may be enduring or temporary, and it may extend over a large or small range of B's responses.

The relation of authority is asymmetrical in that A's initial response (such as a command, request, suggestion, etc.) specifies its own reinforcement, whereas B's does not. The reinforcement is provided by B's response, if the response reduces the state of deprivation or withdraws aversive stimuli for A. For the maintenance of the relationship B's response must be likewise reinforced by A, but the reinforcement is not specified as in the case of A.

The phrase, "in a given situation," indicates that the authority relation is not assumed to be a general one between individuals regardless of time and place. Authority is learned in specific situations, although it may later be transferred to other situations by such processes as stimulus induction. The phrase also implies the reversibility of the relation from one situation to another. This reversibility may violate the usual definition of and feel-

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ing for "authority." For example, one readily accepts the notion of a father's authority over his son, while one would balk at a statement of a child's "authority" over his father. Yet, precisely the same functional relationships may hold in both cases, as we shall demonstrate. It is, therefore, both rigorous and useful to speak of a person's having "authority" over another whenever the same relationships are found, even though this practice might do violence to everyday usage.

The clause, "under the control of deprivation or aversive stimulation," indicates that it is not sufficient to know only the topography of the response of A, but that it is also necessary to specify the controlling variables of the response of A. For example, if A says, "Water, please," in the presence of B, we must know whether the controlling variable of that response is water deprivation or some other deprivation, or whether it is aversive stimulation.

When it is said that the response of A specifies its own reinforcement, we assume that there is "communication" between A and B. Not only does the presence of B, in part, set the occasion for the response of A, but the reinforcement of A's response is contingent upon a response by B. Thus authority behavior is necessarily verbal behavior as defined by Skinner (1957), i.e., behavior the reinforcement of which is contingent upon stimulation of and response by another individual. The definitions of all other terms used in the analysis closely follow the behavioral, empirical definitions given by Verplanck (1957).

BASIC PARADIGM OF AN AUTHORITY SEQUENCE

The central idea in authority relations is that of the reciprocal control and reinforcement of behavior of two persons. Basically, the paradigm is that a response of one person, A, is reinforced by another person, B, and that, in turn, the reinforcing response of B is, itself, reinforced by A. Such an interaction will be called an *authority sequence*. An example is the situation in which Person A asks B for water and B complies by giving A water. Figure 1 gives an illustration of the process. The figure is divided into two parts, the top half representing stimuli and responses directly related to Person A, while the lower half pertains to Person B. The interaction between A and B begins at the far left of the figure with A in a state of deprivation and in the presence of a discriminative stimulus, S_d and $S_B{}^D$. These stimuli set the occasion for the response R_{A1}, "Give me water." S_d is the stimulus, presumably physiological in the example, that results from water deprivation. $S_B{}^D$ is the discriminative stimulus resulting from B's presence in A's environment. $S_B{}^D$ is a discriminative stimulus with respect to R_{A1} in this illustration by virtue of previous conditioning. The response, "Give me water," would not occur unless A were thirsty; nor would it occur unless someone were present to give A water. In some sense, R_{A1} is "appropriate" only in the presence of S_d and $S_B{}^D$, and these stimuli may therefore be viewed as "setting the occasion for" and as having control over R_{A1}. As will be seen, this control is not exclusive, however, for it is the reinforcement of R_{A1} in the presence of the two stimuli that is crucial for the demonstration of authority.

Once the verbal command, "Give me water," has been emitted, it is a stimulus to B. Specifically, it is a discriminative stimulus, $S_{A1}{}^D$, in that it sets the occasion for a response by B that is later reinforced. The major characteristic of R_{A1} is that it specifies

how B can reinforce it. B is in fact "told" that the response, "Give me water," will be reinforced by giving water to A. When B gives water to A, his response, R_{B1}, constitutes the reinforcement, $S_{B1}{}^{R}$ of response R_{A1}. In addition, R_{B1} is also a discriminative stimulus, $S_{B1}{}^{D}$, that sets the occasion for a further response by A. The response in this example is, "Thank you," R_{A2}. In turn, R_{A2}, a generalized reinforcer, constitutes a reinforcement of R_{B1}. Although the reciprocal reinforcement of responses on that part of A and B is terminated arbitrarily in the present example, R_{A2} itself would need to be reinforced by a further response of B, perhaps the verbal response, "You're welcome," or a nod or smile. As the dots to the far right of Fig. 1 suggest, the sequence is theoretically infinite, though in practice it is finite.

The use of only one discriminative stimulus ($S_B{}^{D}$) is greatly simplifying a situation encountered in "real life." The essence of the model is in no way affected by this simplification, however. Quite complex stimuli could be made discriminative—i.e., given "sign" status —in an experimental situation, and an authority sequence from "real life" could be replicated.

In the illustrative sequence of behavior presented, it is important to note that if the sequence is interrupted at any point, predictable consequences follow. Assume, for example, that B does not give water to A, after A has said, "Give me water." This might be because R_{A1} did not result in a discriminative stimulus for B, i.e., it had no "meaning" for B because of lack of previous learning. Or it may be that R_{A1} resulted in a discriminative stimulus that set the occasion for a response other than giving water, perhaps telling A to get his own water. Whatever the reason for not giving water to A, the consequence would be for R_{A1} to undergo some extinction. Similarly, if the sequence were interrupted by A's not emitting R_{A2}, B's response, R_{B1}, giving water, would undergo some extinction, with the result that the probability of R_{A1}'s being reinforced would be decreased. As before, the probability of A's emitting R_{A1} would then be smaller. In both instances where the sequence is interrupted, it is evident that A's authority over B is decreased, at least in this particular situation. It is interesting to note that in the first instance the decrease in A's authority is primarily "because" of a failure attributable to B. In the second instance, however,

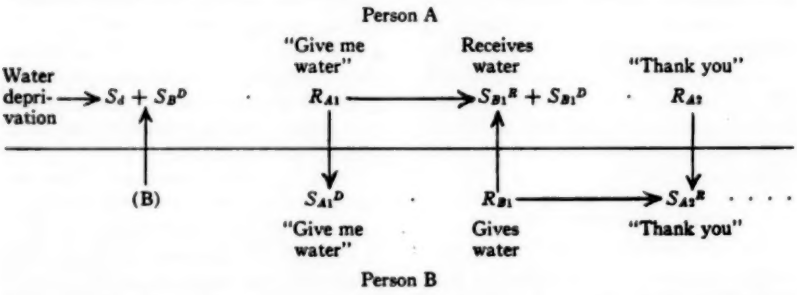

FIG. 1. Authority sequence with initial response under control of deprivation.

A's authority is affected "because" of his failure to reinforce B's response, R_{B1}. The use of "because" here is very loose, of course; no attribution of causality to A and B as persons is intended. Their responses are completely determined, except on their very first occurrence, by their previous reinforcement history and by antecedent stimulus conditions.

In Fig. 1, A's initial response was partly under the control of deprivation. Instead it could have been under the partial control of aversive stimulation. For example, B might have been making some disturbing noise and this aversive stimulus might have set the occasion for the response, "Keep quiet!" It is also true that B's response, R_{B1}, need not necessarily be reinforced by the presentation of a positive reinforcing stimulus. It could have been reinforced by the withdrawal of an aversive stimulus or conditioned aversive stimulus. Figure 2 shows how aversive stimuli might exercise control in an authority interaction.

An aversive noise stimulus, S_n^{av}, and a discriminative stimulus, S_B^D, set the occasion for the responses R_{A1} and R_{A1}^{av}, constituted by the verbal response, "Keep quiet!" and an implied threat carried by the accentuation and intonation of the verbal response. Thus B is presented with a discriminative verbal stimulus, S_{A1}^D, and a conditioned aversive stimulus, S_{A1}^{av}. These stimuli set the occasion for stopping the noise, indicated in the figure as R_{B1}. This response consists of the withdrawal of the aversive noise stimulus, S_n^{av}, and constitutes a negative reinforcing stimulus for A, as well as a discriminative stimulus, S_{B1}^D, setting the occasion for a further response. The response, in this example, is the withdrawal of implicit threat and is labelled, $-R_{A1}^{av}$. This, in turn, is an appropriate negative reinforcing stimulus for B's response, R_{B1}. As in the previous example, the sequence of behavior is stopped at this point. Thus, we have here an interesting case of escape conditioning, with an implied threat as a conditioned aversive stimulus, as well as one of avoidance conditioning with respect to the negative reinforcing stimulus inferred from the threat.

In a manner analogous to that presented earlier, interruption of the behavioral sequence has implications for the authority A has over B. If B, for example, does not stop making noise (perhaps because of the inadequate control of S_{A1}^D and S_{A1}^{av}), A's response, "Keep quiet!" will undergo some extinction and A's authority over

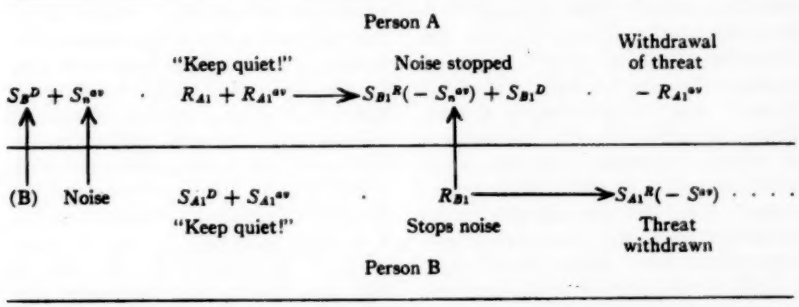

FIG. 2. Authority sequence with initial response under control of aversive stimulation.

B will be weakened under the particular circumstances described. However, B's lack of compliance may of itself constitute additional aversive stimulation for A and thus set the occasion for a new response, perhaps, "If you don't stop that noise, you'll suffer the consequences," which may generate enough additional aversive stimulation for B to make him stop the noise. If this occurred, A would maintain his authority over B, though at some additional expense. A could, of course, alternatively "leave the field," in which case there would be no question of authority over B.

The sequence in Fig. 2 would also be interrupted if A did not withdraw aversive stimulation after B had complied with his command. The consequence would be that R_{B1} would have less likelihood of occurring in the future, a fact which would tend to reduce the probability of occurrence of R_{A1} and R_{A1}^{av} and, therefore, would tend to reduce A's authority over B in this illustrative situation. As was pointed out before, the resulting loss of control of A over B might set the occasion for new responses by A.

In both the illustrations given thus far, certain assumptions have been made which need to be made explicit before the implications of the paradigm are further explored. Some of the assumptions concern the discriminative status of stimuli. For example, it is assumed in Fig. 1 that B is a discriminative stimulus (S_B^D) setting the occasion for the response, "Give me water." But by definition a discriminative stimulus is one in the presence of which a response is reinforced and in the absence of which it is unreinforced. Since A's response, R_{A1}, is not reinforced until some time later, B cannot initially be a discriminative stimulus in the sense of setting the occasion for R_{A1}. What is assumed, then, is some previous learning, i.e., some previous temporal contiguity of response (R_{A1}) and reinforcing stimulus (S_{B1}^R) in the presence of B. The assumption is, however, only one of convenience, and what has been said applies to the free operant situation as well. If A had merely emitted spontaneously the response, "Give me water," in the presence of B (and in the context of deprivation), and if B had responded appropriately to reinforce A's response, the behavioral consequences would have been the same as previously discussed. The only difference is that B would have been a mere stimulus without discriminative properties. However, on *subsequent* occasions B would have discriminative characteristics, assuming further that A's responses had been unreinforced on some occasion when B was absent. The same line of reasoning applies to other stimuli which appear as discriminative stimuli in the figures.

Another assumption is that the reciprocal reinforcement of behavior is a finite sequence. It was stated earlier that the reciprocal reinforcement sequence in the authority relation may be theoretically infinite but that we assumed it was finite in practice. The assumption is difficult to substantiate even though everyday observation suggests that persons in an authority relation do not reinforce each other's responses ad infinitum. There are, of course, cases where reinforcement continues for considerable lengths of time, for example the endless exchange of bows that occurs when a Westerner visits a Japanese home. Nevertheless, the fact is that in our culture the interaction usually stops at approximately the point indicated in Figs. 1 and 2, and that extinction is not a consequence. The reason for this may be that terminating an interaction sequence at a certain point is of itself

reinforcing in that it avoids aversive consequences which would be forthcoming were the sequence not terminated. Thus, for example, in our own culture there are conventions about the termination of an interaction sequence beyond which further responding is punished by the use of conditioned aversive stimuli. As an illustration, it is commonly observed that after compliance with a request, anything beyond a "Thank you" and "You're welcome" results in raised eyebrows, a sardonic smile, or a look of impatience, which may be discriminative stimuli for stopping the interaction. When the stimuli for stopping are not known to one of the parties in the interaction (i.e., are not discriminative), responding may continue for some time, as in the bowing example above. In some situations responding beyond a given point may have the aspect of impertinence and have appropriate aversive results. Alternatively, responding beyond a certain point is unreinforced by society, and an agreed-upon sequence of reciprocal reinforcement becomes a discriminative stimulus for stopping to respond further.

CONTROLLING VARIABLES

Thus far it has been shown how an authority relation between two persons can evolve and either be maintained or be destroyed. The external events (independent variables) of which responses (dependent variables) in an authority interaction are a function will now be discussed. This will be done by grouping variables into general classes and discussing instances under class headings. The basic A–B interaction paradigm will be used throughout.

Reinforcing Stimulus Variables

Stimulus events that have the property of increasing the probability of recurrence of a preceding response are fundamental controlling variables. B's giving water to A and A's saying "Thank you" in Fig. 1 are such events in that they increase the probability of A's again asking B for water when he is later water-deprived, and of B's giving A water, respectively, other variables remaining constant. In other words, certain responses such as "Give me water" have consequences which empirically increase their probability of recurrence and thus in part determine the authority A has over B.

The importance of reinforcing stimuli is more pervasive than has been suggested above, however. The discriminative character of other stimuli is dependent upon their being paired with reinforcement. Thus, for example, in Fig. 1, B's presence would not constitute a discriminative stimulus for A's demanding water, unless it had been temporally contiguous with the reinforcement of A's response. Nor, in Fig. 2, would A's verbal command "Keep quiet!" be a discriminative stimulus for B's stopping noisiness, unless stopping to make noise had been reinforced following the occurrence of the stimulus resulting from A's response. It can therefore be seen that a reinforcing contingency is *necessary* before a stimulus can acquire discriminative properties. This is, of course, not a *sufficient* characteristic: It is also required that the absence of a stimulus be associated with nonreinforcement before it can be a discriminative stimulus. For example, with respect to Fig. 1, it would be necessary that A's response, "Give me water," be unreinforced in the absence of B.

The withholding of reinforcing stimuli following a response is the operation resulting in experimental extinction and, as an observable consequence, produces a decreased probability of response. Illustrations of this have been given previously.

The general properties and the importance of reinforcing stimuli having been pointed out, A and B as the agents or mediators of reinforcement must now be considered.

A as a reinforcer. A can act as a direct mediator of reinforcement or as a conditioned reinforcer. As a direct mediator he can both present positive reinforcers (or conditioned reinforcers) and withdraw negative reinforcers (or conditioned negative reinforcers). A father can reinforce his child for obeying a command by giving it candy. The business executive can reinforce his secretary's compliance with an order by withdrawing an implied threat, much as in the example of Fig. 2. In a similar fashion the traffic policeman reinforces stopping at his gestured command by lowering his arm and, hence, removing conditioned negative reinforcers.

It is evident that, as a direct mediator of reinforcement, A can exercise considerable control over B's behavior. But it is also true that, indirectly, he exercises control over his *own* responses, for the probability of recurrence of his own responses is in part a function of the extent to which he is successful in reinforcing B's responses. Other things being equal, then, A is in some sense the master of his own authority over B. This notion is not a new one, but in the present case it has the advantage of being systematically derivable from the basic model.

A further derivation is that A's probability of successfully developing or maintaining an authority relation over B will in part be a function of the amount and variety or range of reinforcers he has available. The person who can mediate reinforcements appropriate to several states of deprivation can exercise more authority than one who can, say, provide only food (e.g., a parent versus a neighbor). The person who has access to a large range of aversive stimuli can have more authority than one who has not (e.g., a company commander versus a corporal). From a similar consideration it also follows that the greater the amount and range of reinforcers available to A, the greater the range of B's responses he can control, other variables remaining constant. Thus a parent can have wider authority than an older sister who can mete out limited punishment only and who has no money for material rewards.

As a conditioned reinforcer, either positive or negative, A may also exercise control over B's behavior, as well as indirectly over his own. Before he can act as a conditioned reinforcer, however, it is necessary that he have acted on previous occasions as a direct mediator of reinforcement, or, at least, that he be similar to someone who acted as a reinforcer. The important thing to consider is that the mere presence of A can reinforce some of B's responses, no direct reinforcement being given. For example, using the illustration of Fig. 1, it is possible for A to omit saying, "Thank you," and for B's response to remain at considerable strength, provided stimulus attributes of A have become conditioned or generalized reinforcers by virtue of A's having previously, and frequently, reinforced B's responses. However, in order for the attributes of A to remain effective conditioned reinforcers (and discriminative stimuli as well), it is necessary that on occasion A mediate direct reinforcement; otherwise B's operant will undergo extinction. The same applies to A qua A as a negative conditioned reinforcer.

B as a reinforcer. The distinguishing characteristic of B as a reinforcer is that his reinforcing response has no, or only a few, degrees of freedom, as

contrasted with A as a reinforcer. His reinforcing response is specified by A, by definition. To be sure, the discrete topography of his response may vary, but its net effect on A is specified. Thus, for example, B may get and bring water to A in a variety of ways, but the giving of water is the essential property of the response that will reinforce A's request and, therefore, establish or maintain the authority relation.

In a manner similar to A, B may also act as a conditioned reinforcer or negative conditioned reinforcer, in that the authority relation between the two will be maintained or strengthened. This presumes, of course, that B, or someone similar to B, will have appropriately reinforced A's behavior in the past under similar circumstances.

Generalization of A and B as conditioned reinforcers. It has been pointed out that A and B may exercise control over each other's behavior, and thus maintain or strengthen an authority relation, in their capacities as conditioned reinforcers. It is also true that conditioned reinforcement may be effected by individuals other than A and B who have physical properties similar to A and B. Thus, an officer never before encountered may act as a conditioned reinforcer of an enlisted man's compliance with an order, by virtue of the fact that he has properties similar to those of other officers who have reinforced the same response. The dimensions of similarity in this example might be the uniform and emblems of office; or the relevant dimension might be physical characteristics of verbal operants, e.g., "'ten shun!" Similarly, the authority of policemen is partially maintained, even though never before seen personally, through stimulus induction. How often has one slowed down at the sight of an unknown policeman whose back was turned?

Deprivation and Aversive Stimulus Variables Affecting A

As stated in the definition of authority, A's initial response (order, command, request, demand, etc.) is partially under the control of deprivation or aversive stimulation, other control being exercised by discriminative stimuli (e.g., the presence of a B). This results from the fact that certain responses of the human organism are typically followed by specific consequences under certain conditions agreed upon by the social community, and that when this occurs the probability of occurrence of these responses will be a function of the deprivation or aversive stimulation paired with the reinforcing consequences. Thus the response, "Give me water," has a greater probability of occurrence under water deprivation than under satiation because other organisms are more likely to have provided water when A emitted this response and was thirsty. It should be noted that deprivation and aversive stimulation do not *necessarily* exercise control over the response. The control results from the fact that other organisms are predisposed by "societal consensus," so to speak, to respond in certain characteristic ways. This predisposition of other organisms is analogous to certain automatic consequences of the nonanimal environment. For example, picking and eating an apple is automatically reinforcing when the organism is food-deprived, though not if he is satiated. Thus, food deprivation would come to control picking and eating an apple. A similar line of reasoning applies to aversive stimulation, though in this case reinforcement consists in the withdrawal of an aversive stimulus.

The relations holding between deprivation (or aversive stimulation), response topography of A, and reinforc-

ing response by B are stated in idealized terms. This is especially true with regard to A's response topography "specifying" its reinforcement. It is conceivable, for example, that the response, "Give me water," specified not a state of water deprivation which could be reinforced by water but rather a demand for submissiveness on the part of B, the state of deprivation being for something other than water. In such a case the content of A's response does not clearly specify the appropriate reinforcing stimulus—at least the words used do not clearly convey the state of A's deprivation. However, other aspects of the verbal response than the words may serve as appropriate discriminative stimuli for submissiveness (i.e., sheer compliance). The imperative mood of the response, for example, may serve this function. Whether it does this effectively on a particular occasion is, of course, a function of appropriate previous differential reinforcement. To put it somewhat loosely, it is a function of whether B has learned that use of the imperative mood is a "sign" for compliance regardless of the specific content of A's response.

Discriminative Stimulus Variables

In the discussion of Figs. 1 and 2 the role of discriminative stimuli was made explicit. We wish to expand the discussion at this point and focus specifically on the discriminative stimuli that control A's initial response. The discriminative stimulus characteristics of responses by A and B will be omitted, as they are evident.

Two general groups of discriminative stimulus variables controlling A's initial response may be considered, stimulus characteristics of B and situational stimuli, excluding B. A general characteristic of B that may serve as a discriminative stimulus is his being an organism with the potentiality of responding. Without another person's being present, a response by A cannot be reinforced, and A cannot exercise any authority. There are, however, other relevant aspects of B. One is B as a particular individual, i.e., the stimulus characteristics of a B who has previously reinforced A's response, as opposed to a B who has not. A second is B as the incumbent in a particular role, as an office boy or corporal, for example. In this instance characteristics of B serve as discriminative stimuli for a comparatively narrow range of responses by A. In other instances characteristics of B may set the occasion for one class of responses only; for example, the elevator boy is a discriminative stimulus for the response, "Take me to the sixth," only. Thus we may think of B as having discriminative stimulus characteristics that exercise control over A's responses with different degrees of specificity. The specificity of control exercised is a function of the extent of differential reinforcement carried out in the presence of particular characteristics.

The second group of discriminative stimulus variables are situational variables. They include virtually all relevant stimuli not directly pertaining to B. Some situational variables are part of the purely physical environment. Thus, the request, "Take me to the sixth," has a low probability of being reinforced in the absence of an elevator. Similarly, "Give me water," will usually have a low probability of occurring without a source of water in the immediate environment. However, in an instance of this sort, deprivation may become so severe that it exercises almost exclusive control. The "Water, water!" of the wounded soldier on the deserted battlefield is an example. Other situational variables are of a more "social" character in that the

presence of other persons, or of persons having particular types of interaction, has a controlling discriminative stimulus function. Certain kinds of commands or requests are not issued to one's wife at home in the context of a cocktail party (and would go unreinforced, if issued), though they are issued and reinforced when just family members are present. Orders may be successfully given to an employee at the office, though not at the country club.

Whether discriminative stimulus control is exercised by B proper or by situational variables, it will be achieved only after differential reinforcement. The controlling stimulus variables may, of course, be of great complexity and require considerable training. For example, an authority response, R_{A1}, will be reinforced only if Stimuli I, J, . . . , *or* N are present, *and* if Stimuli B and C are present, *and* if Stimulus R is absent. The situation is analogous to those encountered in concept formation studies (e.g., Bruner, Goodnow, & Austin, 1956). In the present instance a response is reinforced only in the presence of particular stimuli, whereas in concept formation studies a response is said to be "correct" in the presence of some stimulus combinations and "incorrect" in the presence of other combinations.

Since complex stimulus control of this type requires considerable training with differential reinforcement, it follows that in early stages of training control will be imperfect. Some variables, in the absence of others which are necessary for reinforcement, will exercise some control over a response, even though it will not be reinforced. It is also possible that during the course of differential training "irrelevant" variables would exercise some control over an authority response. This inappropriate control of stimuli results when a response is reinforced in the presence of both appropriate discriminative stimuli and irrelevant other stimuli. These stimuli then acquire some discriminative stimulus capacity. Their control is eventually weakened and abolished during further differential training.

THE FUNCTIONAL INTERRELATION OF AUTHORITY SEQUENCES

The classes of variables of which authority is a function have been specified for a two-person situation. In large groups new problems arise with respect to the arrangement of authority sequences within the group. The problems associated with relating authority sequences arise from the basic characteristics of authority and the presence of more than two persons in the total situation. This section is addressed to these problems and consists of an analysis of the ways in which authority sequences are patterned within the limitations imposed by the assumptions of authority as outlined in the preceding section.

In order for two authority sequences to be functionally related, one of the following conditions must be met: (*a*) authority sequence, K, or some part of it, controls authority sequence, L, or some part of it; (*b*) all or some part of authority sequences, K and L, are under the control of a common (or similar) variable (variables); and (*c*) two simultaneous initial responses are made that specify incompatible reinforcement responses by B.

For purposes of exposition, these will be regarded as distinct cases of authority sequence interrelationships and will be discussed separately.

Case I: One Sequence Exercises Functional Control Over Another

There are a number of ways in which an authority sequence exercises control

over a succeeding sequence, but it is important to note that an all-or-none relationship of control is not implied. The whole or any part of an authority sequence may control a succeeding sequence. This control may be either partial or complete and affect all or part of the succeeding sequence. Discussion will be limited to two basic ways in which two sequences may be functionally related.

Situation where a response in Sequence K controls a response in Sequence L. Authority sequences are frequently related by virtue of the fact that a response in the first sequence controls a response in the second. Generally speaking, with exceptions to be noted, the response by B in the first sequence is the initial response in the second sequence. For example, when a father orders his daughter to tell baby to be quiet, the response of daughter saying "quiet" to baby is B's response in the sequence father-daughter, and also the initial response in the sequence involving daughter-baby. Figure 3 gives an illustration of how the process might operate.

A's response, "Tell Johnny to be quiet," is under the control of aversive stimuli from noise being made by the baby and of B as a discriminative stimulus. B's response of going and telling baby, "Daddy says, 'be quiet,'" is under the control of the stimuli of A's initial response, i.e., of a discriminative stimulus ($S_{A1}{}^{D}$) and of a conditioned aversive stimulus (S^{av}) consisting of an implied threat of punishment for noncompliance. B's response, R_{B1}, unlike responses in the dyadic situation, does not directly reinforce A's initial response, R_{A1}. Rather, it constitutes stimuli for C to stop making noise, R_{C1}. It is C's response, R_{C1}, that reinforces the original response of A, i.e., R_{A1}. This in turn sets the occasion for A to make a response that reinforces B's response; i.e., $R_{A2}(-S^{av})$ constitutes reinforcement for R_{B1}. The form of this response might be the removal of the implied threat. In order for the behavior to be maintained, C's response, R_{C1}, must also be reinforced. In the figure this response is a discriminative stimulus for B, who makes a response something like "Good boy," R_{B2}, which reinforces the response of stopping

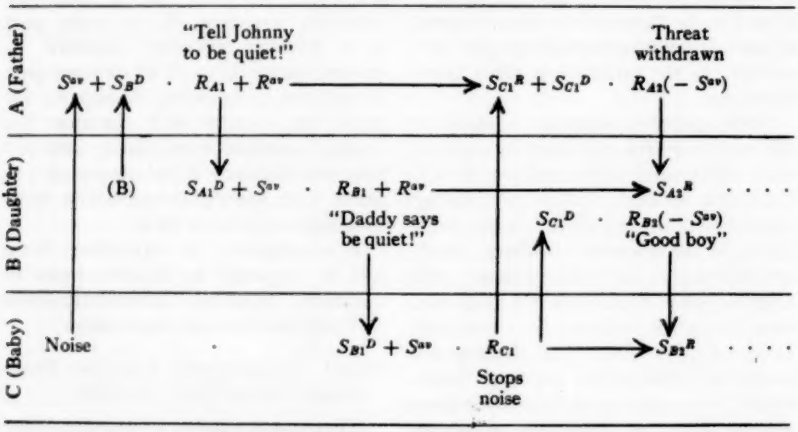
A (Father)
B (Daughter)
C (Baby)
"Tell Johnny to be quiet!"
Threat withdrawn
$S^{av} + S_B{}^{D}$ · $R_{A1} + R^{av}$ → $S_{C1}{}^{R} + S_{C1}{}^{D}$ · $R_{A2}(-S^{av})$
(B)
$S_{A1}{}^{D} + S^{av}$ · $R_{B1} + R^{av}$ → $S_{A2}{}^{R}$ . . . .
"Daddy says be quiet!"
$S_{C1}{}^{D}$ · $R_{B2}(-S^{av})$ "Good boy"
Noise
$S_{B1}{}^{D} + S^{av}$ · R_{C1} → $S_{B2}{}^{R}$ . . . .
Stops noise

FIG. 3. Response-related authority sequences.

noise, R_{C1}, by removing an aversive stimulus.

Functionally related series of this general sort take many different forms. For example, in Fig. 3, it would be possible for the second response of the father, $R_{A2}(-S^{av})$, to take the form "Thank you, children" and constitute reinforcement for not only the response of the daughter, R_{B1}, but also for the response of the baby, R_{C1}. In such an event it would be unnecessary for the daughter to reinforce the baby. Another very common situation in command chains arises when, for example, the president of a company asks the vice-president for a report, and the vice-president asks a department head for the report. In this case the department head gives the report to the vice-president, who in turn gives it to the president. Here the action of the department head, C, does not directly reinforce any response by the president, but rather of the vice-president.

An inherent characteristic of situations involving a chain of command is that there is some delay in the reinforcement of A's initial response. This delay in reinforcement has implications for the readiness with which such responses are conditioned. Generally, conditioning of the response is a decreasing function of the delay between response and reinforcement. In practical situations there are techniques available to "help A across" such a time lag by presenting conditioned reinforcers during the delay period. For example, B can supply comments such as, "The report will be ready at three," "Yes, sir," "Right away, sir," "I'll attend to it immediately," and so on. Periodic "progress reports," frequent personal communications, and verbal reassurances are probably manifestations of the utility of supplying some supplementary conditioned reinforcement to A where the situation involves a long delay in reinforcement. This is in accord with the findings of Perin (1943a, 1943b) and Grice (1948) on the effects of removing conditioned reinforcers upon the delay of reinforcement gradient.

Situation where a response in Sequence K is under control of Sequence L. In this situation the whole of one sequence constitutes part of the situation for a second sequence. When the second sequence can be shown to be, at least in part, under the control of the first sequence, then the two sequences are functionally related. Consideration is limited here to the situation in which no individuals who are in the first sequence are also in the second.

An authority sequence frequently controls a response in another sequence either through "imitative" mechanisms —that is to say, by serving as a discriminative stimulus—or by increasing deprivation or aversive stimulation. Consider, for example, a group of mothers and children, where the children are playing in the mud. The first mother tells her child to stop playing in the mud. The child complies and is rewarded. This authority sequence may constitute a conditioned aversive stimulus for the second mother. The aversive stimulus may be social disapproval of not following the first mother's "example." The first sequence may also be a discriminative stimulus setting the occasion for the second mother's telling her child to stop playing in the mud. If the child complies, the aversive disapproval (perhaps only implied) of the first mother is withdrawn, and the second mother's behavior is reinforced.

Case II: A Common Variable Exercises Functional Control over Two or More Sequences

Probably the simplest manner in which authority sequences are func-

tionally related is by sharing a common controlling variable. Sequences interrelated in this way are found most commonly in large groupings of face-to-face interactions where more complex ways of arranging authority sequences becomes unwieldy. Two types may be considered: (*a*) where an initial response by A specifies the behavior of several people, and (*b*) where two or more initial responses specify a single reinforcing response on the part of one person.

Situation where an initial response specifies behavior of several individuals. The situation in which one individual, A, directs a response to a large number of individuals, B, C, ... , N, is a common one. The authority sequences in such an event are all under the control of the variables affecting the initial response of A. For example, when a drill sergeant calls a company of soldiers to attention we have a situation where the response, "Attention!" specifies as its reinforcement the behavior of several individuals. Each pair formed by the sergeant and an individual soldier may be thought of as an authority sequence, assuming, of course, that they all come to attention and are reinforced by some behavior of the sergeant. These authority sequences are functionally related by the fact that they are all under the control of whatever variables determine the response of the sergeant, namely, calling the company to attention. The situation is illustrated in abbreviated form in Fig. 4. An interesting implication of this type of authority situation is that the authority response of A is likely to remain in considerable strength and to be very resistant to extinction by virtue of the fact that the more other persons his response is addressed to, the more likelihood there is for some compliance and, hence, the more likely he is to get some reinforcement. In some limiting cases, of course, it is possible that the compliance of *all* Bs is the sole effective reinforcement for A. In such cases, the Bs can be treated as a single entity. It could be predicted, then, that certain military men, certain types

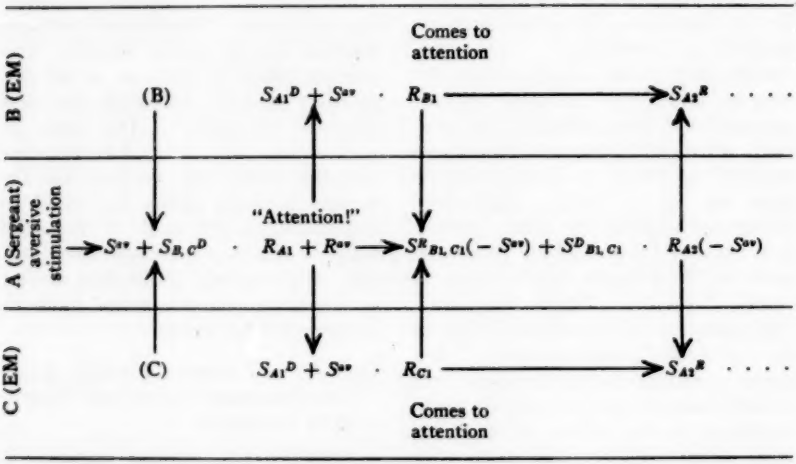

FIG. 4. One-to-many authority sequences.

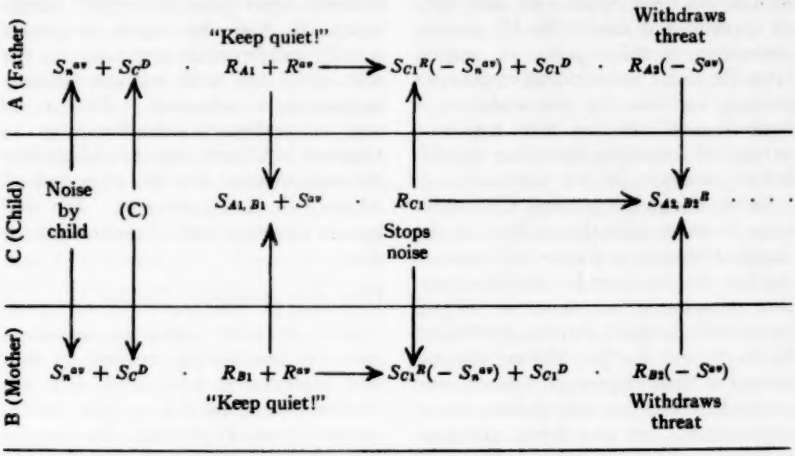

FIG. 5. Many-to-one authority sequences.

of supervisors and foremen, teachers, housewives with large families, etc., would on the average have greater strength of authority responses in these situations than others, because there is a greater probability of their being reinforced. These are in fact persons who are often labeled "bossy."

Situations where two or more initial responses specify a single reinforcing response. Under certain circumstances to be specified below, two or more individuals may simultaneously initiate an authority sequence (give a command, request, suggest, etc.) with a third party, in which both of their responses specify the same behavior on the part of the third party as reinforcement. The example of a father and mother both saying, "Keep quiet" to their noisy child at the same time is diagramed in Fig. 5.

The sequences are here functionally related by the fact that R_{C1} is part of both sequences. Since every response in a sequence exercises some control over the sequence, these sequences are under the control of the common variables related to the common response. The sequences are also related by the fact that the aversive stimulation in partial control of R_{A1} and R_{B1} is from the same source.

This type of relation between authority sequences is subject to more restrictions than any of those previously discussed. The most important restriction is that the two initial responses by A and B must specify a response on the part of C that will reinforce both initial responses. A and B, of course, need not specify an identical response, though in practice this may often be the case. It is only necessary that the responses specified be equivalent in their effects. Figure 5 illustrates a common way in which this arises, namely, A and B are under the control of a common aversive stimulus, the noise of a child. Under other circumstances A and B could be under the control of a common deprivation. Other more complex and subtle relations are not uncommon. For example, an audience in the presence of a good performer may be under the con-

trol of common stimuli so that they all applaud and shout "Bis!" and the performer complies with an encore. Here the exact specification of the controlling variables for the audience is somewhat difficult, and there may be a variety of variables operating on different members of the audience.

Other things being equal, C is under more aversive stimulation than in the simple authority sequence by virtue of the fact that he is under multiple aversive stimulation, as shown in Fig. 5 by the two implied threats symbolized by $S_{A1}{}^{av}$ and $S_{B1}{}^{av}$. Making the assumption that degree of control and amount of aversive stimulation (or of deprivation), up to a limit, are positively correlated, it follows that compliance will be an increasing function of aversive stimulation (or of deprivation).

Another feature to note in these types of relationships between sequences is that A and B may be viewed as a "coalition" under the control of common deprivation or aversive stimulation. When they do not act as a coalition, i.e., when they are not under common deprivation or aversive stimulation so that the initial responses specify incompatible responses on the part of C, the total relation becomes impossible to complete. That is to say, contradictory behavior may be required of C such that it is impossible for him to reinforce the responses of A and B simultaneously. We call such a situation one of *authority conflict.*

Case III: Authority Conflict

Two or more authority sequences may be functionally related in that one sequence is associated with the interruption of another or that the sequences mutually preclude the completion of each other. Specifically, sequences interfere with terminal reinforcements. In such cases there exists *authority conflict.*

Figure 6 provides an illustration. The situation is that of two bosses descending simultaneously upon their joint secretary late in the day with rush jobs. The typing jobs are of such a nature that only one can be completed. The two bosses, A and C, issue re-

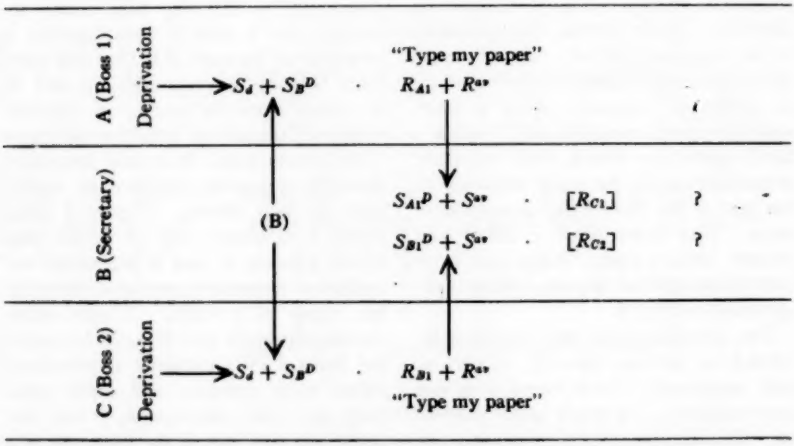

FIG. 6. Authority conflict situation.

quests, R_{A1} and R_{C1}, with implied threats for noncompliance. These, let us assume, constitute discriminative stimuli plus aversive stimulation for the secretary, B. (The consequences to be discussed do not require this assumption, but it is made for the sake of reality.) Since B can comply with only one of the requests, there exist for her two incompatible (conflicting) response tendencies. These response possibilities exist for her: (*a*) she can comply with A's request and thus reinforce his response; (*b*) she can comply with C's request and thus reinforce his response; or (*c*) she can comply with neither request and therefore reinforce neither A's nor C's response. The consequences of the first two possibilities are analogous, while those of the third are different.

If B complies with A's request and therefore reinforces his initial response, A's response will have an increased probability of recurrence in the future under similar circumstances and C's response will tend to undergo extinction. If we now assume further that when C alone—that is, in the absence of A—makes a request of B, she complies and his behavior is reinforced, it follows that A will become a negative discriminative stimulus for C. In sum, if B reinforces C in the absence of A and does not reinforce him in the presence of A, C will "learn" to make his requests in the absence of A. In practice, this may lead to a scheduling of authority responses, as when Boss 1 directs the secretary mornings and Boss 2 directs her afternoons.

The factors which result in B's reinforcing A's behavior in preference to C's are of interest. One factor is that A may have reinforced B more frequently than had C in the past for the same or similar responses, with the result that A's response exercised greater control over B. Another possibility is that A, perhaps because of powers associated with his rank or position, could give B greater reinforcement than could C, frequency of reinforcement by A and C being equal. It might also be that, even though having reinforcing powers equal to those of C, A made greater (and "better") use of generalized reinforcers. His expression of thanks, for example, might generally be more reinforcing (it might be less perfunctory). Another factor may be that A, as opposed to C, has acquired conditioned reinforcing properties under circumstances quite different from the boss-secretary relation. Finally, if we assume a completely free operant situation and no previous learning histories, it could be that B's response to A merely has a higher operant level than the conflicting response to C.

The second case to consider is when B complies with and reinforces neither A's nor C's request. In such an instance it is clear that both A's and C's initial authority responses will undergo extinction. However, it is clearly possible for the secretary's inactivity to set the occasion for new responses on the part of A or C or both which will be reinforced. Thus, A and C might say, "Type A's paper now and C's tomorrow." Furthermore, it is possible that, if A and C, when interacting alone with B, are reinforced in their requests, they will come to make their requests only in the absence of the other. This follows from the operation of differential reinforcement and of the resultant control exercised by a negative discriminative stimulus.

What the antecedents are for nonresponse on the part of B are many and need not be enumerated. Generally, however, the situation is that both A's and C's responses and situational stimuli exercise the same degree of control over B's responses. To

use a vector analogy, the vectors representing B's two response tendencies are of equal length and at 180 degrees to each other.

In the discussion of authority conflict, attention has thus far been limited to the consequences of B's responses upon the behavior of A and C. It is evident, however, that the types of conflict envisaged will have effects upon the behavior of B. One effect is that, when B reinforces the behavior of A in preference to C's and is in turn reinforced by A, her response to A will have an increased probability of recurrence, whereas any response tendency toward compliance with C's request will be weakened under similar circumstances. When B responds neither to A nor C, whatever response tendencies existed at the time will undergo extinction since they will not be reinforced. In both of these cases it is interesting to note that the conflict of responses on the part of B is self-reducing, in one case because one of the two response tendencies is weakened and in the other because both are weakened. However, the existence of conflict may have other side-effects.

If it is assumed that being in conflict results in aversive stimulation, certain consequences can be predicted. Under this assumption the secretary in the illustration will be subjected to aversive stimulation. Furthermore, this aversive stimulation will be contingent upon her responding or tending to respond to A and C. That is to say, the conflict and consequent aversive stimulation exist solely *because* of her competing responses (of course, phenomenally, B may perceive A and C as being instrumental in her conflict). It follows, then, that A and C, as well as other aspects of the total situation, will become conditioned negative reinforcers and that B will tend to *avoid* them. Making the further assumption that degree of conflict and resulting aversive stimulation are positively correlated, it also follows that the strength of B's avoidance response will increase with increasing degree of conflict. Since degree of conflict will be a function of the strength similarity of B's two incompatible response tendencies, it may be concluded that the more nearly equal the response tendencies, the greater will be the avoidance of A and C.

The preceding analysis of authority conflict has dealt exclusively with the case in which only one of two (or more) incompatible responses can be emitted by B. It can, however, also happen that one response will be emitted first and that a second will subsequently be emitted upon the completion of the first. Thus, the fictional secretary could have typed A's letter first and, upon completion of that job, could have typed C's. In such a case both A's and C's authority responses will be reinforced. However, it is evident that some delay is entailed in the reinforcement of C's responses. The consequence of this will be to weaken the effect of the reinforcement, the magnitude of the net effect being inversely proportional to the amount of delay.

SUMMARY

We have suggested the following definition of authority: A person A has authority over B, in a given situation, when a response of A, under the control of deprivation or aversive stimulation and specifying its own reinforcement, is reinforced by B. Authority, so defined, has been analyzed as a function of the following variables:

1. Reinforcing stimulus variables
   (*a*) A as a reinforcer
   (*b*) B as a reinforcer

(*c*) Generalization of A and B as conditioned reinforcers
2. Deprivation and aversive stimulus variables affecting A
3. Discriminative stimulus variables.

A paradigm of an authority sequence was analyzed in terms of these variables. Series of functionally related sequences were defined as sequences under the control of one another or of common variables. Three classes of functionally related sequences were analyzed:

1. Where one sequence exercises functional control over another
2. Where a common variable exercises functional control over two or more sequences
3. Authority conflict.

The functional analysis of authority that has been presented places primary emphasis upon the reciprocal nature of authority interactions and, by so doing, suggests how authority evolves, is maintained, and may be weakened.

As the analysis suggests, it is actually improper to speak of the locus of authority, except perhaps for "shorthand" purposes. Authority is behavior and is a function of certain operationally defined variables. By adopting this functional approach, it should be possible not only to account for observations that have been made about authority, but to deduce systematically the consequences of manipulating variables in specified ways.

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ON DISCRIMINATION EXPERIMENTS
I. TWO LOGICAL STRUCTURES

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Among the remaining notes and papers of Max Wertheimer were two manuscripts on discrimination experiments and problems regarding absolute and relational learning, of which this is the first. Much has, of course, occurred in the more than fifteen years since they were written, but the main issues are still alive, and it is felt that the views represented here are still of interest. Unfortunately, the papers were by no means in final form. A certain amount of editing was thus inevitable, to give some continuity and coherence to the discussion. I have attempted to keep all changes to a minimum, making them only where coherence or clarity demanded, and where no questions of interpretation were involved. A few sections of this paper were so fragmentary that it seemed impossible to present them essentially as they were. Here I have taken the liberty of presenting my own interpretation of what was meant; these sections are bracketed. Wherever comments by the editor seemed called for, they are printed in italics.

It should be noted that Wertheimer himself was still far from satisfied with many of his formulations as they stood. Had he brought the paper to completion himself, I am sure that much would have been very different; however, at least it represents the direction in which his thoughts were going.—LISE WERTHEIMER WALLACH [2]

Let us attempt to formulate some essentials of the *logical structure* of discrimination experiments.

Suppose an animal learns to respond to a pair of stimuli differing "only" in pitch, brightness, or size, etc., the stimuli of the pair differing considerably. The learning may establish a positive reaction to b, a negative reaction to a, or two different responses to the two stimuli. Some time later, just after training, or perhaps one day later, a test trial is given, say, with the same pair.

I shall name the two stimuli of the first test trial on the second day x and y, x in this case being the "same" as a, and y the "same" as b. Suppose that y is recognized as b, and x as a. Or, more neutrally, suppose that y is reacted to in the same way in which b was reacted to on the first day.

LOGICAL STRUCTURE I

The following possibility suggests itself for understanding the process which leads to a correct choice on the test trials. It may be that the decisive factors are $x = a$ and $y = b$. A simi-

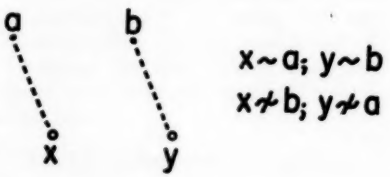

FIG. 1.

[1] Posthumous publication.

[2] I would like to express my appreciation to the New School for Social Research, for both financial aid and the encouragement and cooperation I have received there.

lar explanation holds when x is similar to a, and y is similar to b [3] (see Fig. 1).

THE DIFFICULTY OF MEMORY FOR ABSOLUTE QUALITIES AND THE EXACT SIZES OF RELATIONS

Memory (recall, recognition, etc.) for absolute qualities like absolute size, absolute pitch, is, especially after a considerable time interval, pretty bad, vague, and liable to be shifted by external influences.

a. Suppose that on the first day only *one* pitch, brightness, color, or size is given (and perhaps a name or a reaction learned to it). If, on the second day (or even after an interval of several minutes), a stimulus is given which is either the same or slightly different from the first one, most people are entirely unable to say whether it is just the same pitch, brightness, color, or size as the preceding one. (Consider, for example, the difficulty one would experience in trying to match exactly a piece of cloth in the store to the suit one has left at home.) People will frequently hesitate and identify a new stimulus wrongly as the original, or they will judge that the same stimulus is different from the original one.

b. Further, if shortly before the test stimulus we introduce a new stimulus or series of stimuli, then the relation of the test stimulus to these preceding stimuli can be more important than its relation to the original stimulus. If, for example, Tone G is given on Monday, and on Tuesday Tone G is preceded by F, then G may be judged too high. If, on the other hand, Tone G is preceded on Tuesday by Tone A, G may be judged too low.

c. Memory for the exact size of relations is similarly poor (unless outstanding features come into play).[4]

The rest of this section was too fragmentary to present as it was. The following is my interpretation of what was intended:

[Suppose that on the first day there are presented a small line and a large line, or a low note and a high note, and that on the second day the subject is asked to judge whether the difference between two stimuli is the same as the day before. Such a judgment will be very difficult.

[But if instead of asking whether the exact sizes of the relations are the same, one asks whether the direction of the relations are the same, judgment is very much easier. If on the first day the first tone is lower than the second, and on the second day it is higher, it will be easy to recognize that the direction is not the same. Remembering the direction of relations is much easier than remembering their exact "sizes" and absolute qualities.]

[3] But this picture is certainly not sufficient to tell the whole story. It is not possible to deal simply with the connection $a - x$ on the one hand, and $b - y$ on the other. In order that positive and negative responses—or, more generally, different responses—may be aroused by a and b in the learning trials, it is implied at least that a and b are sufficiently different to be taken, reacted to, *as* different. The same holds true for x and y. Hence the actual differences between a and b, and between x and y are essential, rather than only the connection of x to a and y to b. These differences become basic in the *second* structure.

[4] Memory for absolute qualities and for the exact size of relations changes for the better if "outstanding" qualities come into play. Some examples: (*a*) On Monday present a mixture of red and yellow (say 260° red and 100° yellow); test recall on Tuesday. Memory for this mixture is much poorer than memory for a pure red or a pure yellow. (*b*) Memory for and recognition of an angle of 80° is not as good as that of an angle of 90°; similarly different is the fate of a 5° angle from that of a 0° angle. (*c*) Vertical and horizontal positions are outstanding in memory. (*d*) A point midway between two points on a line is likely to be better recalled than a point which is to one side.

d. The time interval is important in these cases, and it affects memory for absolute qualities and for relations differently. To recognize a *y* as a *b* is easy if the time interval between *y* and *b* is very short. If we increase the time interval, recognition becomes more and more uncertain, the recognition curve falling off very rapidly. On the other hand, the memory for the direction of a relation, such as being bigger than, or being above, is, after a day's interval, relatively very much better.

To base a theory of memory of relations on absolute memory is, then, to explain things by demanding very much more (by setting many more conditions) than is needed or probable. *This point is discussed further in a later section "Comparison of Logical Structure II and Spence's Treatment of Transposition."*

ABILITY DISTINGUISHED FROM ATTITUDE

It is necessary to distinguish two problems when we study the characteristics of absolute and relational choice.

The *first*, and generally regarded as the outstanding, problem concerns the ability of the animal to recognize a new stimulus as similar to the old one, or as dissimilar to it. If we raise this question in connection with absolute and relational choices, experiments of the following kind are appropriate: An animal learns by the Pavlov method to respond to *one* note, and it is afterwards tested for its memory of the absolute stimulus. This can be compared with the animal's memory for learning to respond by the same method to the *higher* of *two* stimuli. The question then is whether the animal in each case will be able after a time to find out which one is the correct stimulus. What errors will be made, and what will be the range of stimuli considered "correct"? How will the forgetting curves for the absolute and relational stimuli compare? This is the problem of acuity; the purpose is to find out what is the best discrimination under given conditions.

The *second* problem raises an issue of a different kind. In order for the animal to "respond to the new stimulus in the learned way," the decisive fact is not only whether the animal recognizes the new stimulus as similar to the old one, or as somewhat different. Equally decisive is whether the animal is willing, whether he is in the mood, whether he is in the habit of reacting to new stimuli in the same way as to old ones, in spite of a recognized difference. In human terms, the animal may have the tendency, or it may decide, to make the same response in spite of a recognition of some degree of dissimilarity.[5]

Consider, for example, the tendency under certain personal conditions to be exactly correct, to be fearful of doing anything when the conditions deviate in the slightest from what is known, to stick to "exact identity," and so on. Certain patients with brain lesions confronted with the task of matching yarns of similar nuance to a selected red and green are sometimes extremely fussy. They reject any test woolens which are in any way different. If the hue is

[5] So long as the gradient and the level (see Paragraph *b* of the section on "Factors Involved in Each of the Logical Structures" below) are not very much changed, the right response is probable (especially after long time intervals), not because the animal is responding in spite of a change in the situation, but because memory is, to begin with, not precise. Within a range of changed gradient and level, the difference between test and training situation may not be noticed at all. It is only if the change exceeds such a range that the question may arise whether one is willing to make or try the learned reaction on the ground of the similarity to the original *in spite of* the difference from the original.

the same, but the brightness is somewhat changed, they refuse to match. In studies with children, it sometimes looks as if, when the child is frightened or sternly treated, he develops a tendency to avoid any deviation from command, or from the learned, permitted response.

On the other hand, different attitudes can be observed in children as well. Some, in a certain mood, do not seem to be very much bothered about the response. If the situation is in general the same, they repeat the response generously, frivolously, loosely, even if there is little similarity to the original situation.

Such differences seem to depend on moods, personal characteristics, the social atmosphere, the experiences coloring the field, confidence in the nature of the events, and so on. Some exhibit an attitude of the first kind, which means in effect: "The events in the world are such that if you want to avoid dangers or mistakes, you have to apply a learned response only to exactly the same situation, and not if there has been any change." Others exhibit a free and senseless confidence: "If there is any similarity—go ahead." This difference in approach has some connection with the very real difference mentioned by Bertrand Russell between rats in some laboratories who rush about and jump ahead, and rats in other laboratories who sit still and "think."

The range of responses is, then, determined by at least two different factors, and their effect on the range is not the same. Further, the first factor, the ability to decide, to find out whether the new stimulus is similar or different to such and such a degree probably plays a role only when conditions for the second factor (the behavior attitude) are optimal. Also, the second factor does not depend upon time in the same way as the first.

From the standpoint of operationism there may be an objection to the differentiation of the two factors on the ground that there seems to be no objective way of stating the first without using the second. That is, we cannot decide upon the first question in any other way than by studying responses which involve the second problem as well. But there *are* ways of operationally differentiating. This is certainly so in experiments with humans, if we distinguish between experience and action (or, in terms of objective behaviorism, if we distinguish between answers to questions like "is this the same or not?" and "real action" like getting food). We may agree that the study of the first question in animal experiments can only be by way of studying responses. But within these responses there are observable differences of behavior, often quite strong, which correspond to the two types of attitudes described above.[6]

LOGICAL STRUCTURE II

If we formulate the essentials of the second logical structure, we get a picture very different from the first one (see Fig. 2). Logically, we have aRb (and bR_1a); we have xRy (and

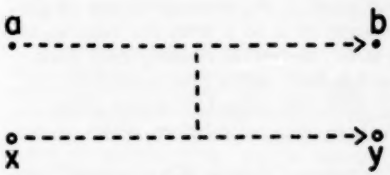

FIG. 2.

[6] The situation seems to some degree similar to the differentiation which every physiologist makes between questions of acuity and so-called disturbing factors in experiments, such as resistance of the animal, distractability, and so on.

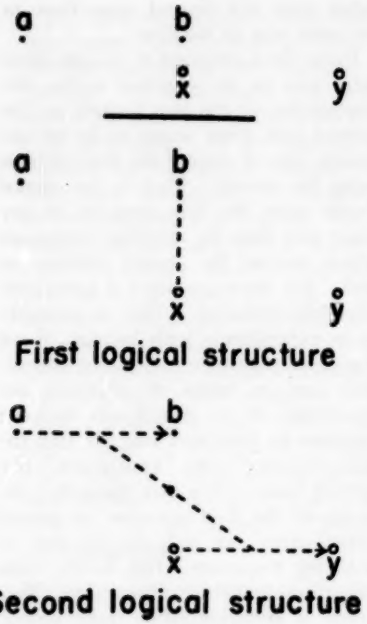

FIG. 3.

yR_1x). There is a correspondence between the R of x-y and the R of a-b. Here y is identified with b if it has the same position in the relational structure x-y that b has in the relational structure a-b. Instead of the individual correspondence of y with b and x with a, the basis of reactions in test trials is the correspondence of the relation of x to y with the relation of a to b. Instead of treating each stimulus for itself, as the first structure (Fig. 1) does, the second structure (Fig. 2) deals in terms of relations within pairs.

CONDITIONS UNDER WHICH THE TWO LOGICAL STRUCTURES WORK IN OPPOSITE DIRECTIONS

In the aforementioned cases, both theoretical assumptions would lead to the same prediction. There are, however, other experimental conditions under which the two may work in opposite directions.

There is, for example, the critical experiment of Köhler in which $x = b$ in absolute terms but $x = a$ in relational terms (Fig. 3).

For the first logical structure, the simplest formulation is $x = b$, and y is a new, strange stimulus. And we shall have to expect, in terms of the first logical structure, absolute choice. If b was the positive training stimulus (e.g., containing food), x will be reacted to as positive.

For the second logical structure, y has the same role in the pair x-y that b had in the pair a-b. In terms of this structure, we would therefore expect relative choice, y being reacted to as positive.

In such cases it is possible to find out by experiment if the results agree with one or the other theoretical structure; it is also possible to introduce experimental variations which may increase the weight of the absolute or the relative attitude. *These are discussed further in a later section, "Conditions Favoring Transposition or Absolute Reaction."* A further possibility for an experimental test is that in terms of the second logical structure all variations which decrease the ease of the comparison of x and y or a and b in the pair should be factors making the results worse. And factors improving this possibility should improve the results. In terms of the first logical structure, such variations should have no effect, since the animal does not look for a relation between the stimuli in a pair but only for a relation between *each* of the test stimuli and the traces of each of the original stimuli (involving a comparison of two items with a long time interval between them).

In order to find and to study the real causes at work, we may also use, for

example, the point mentioned above in the section, "The Difficulty of Memory for Absolute Qualities and the Exact Sizes of Relations." If the forgetting curve is different in the two cases, and if memory for absolute qualities decreases more rapidly than for relational qualities, the following experimental proposal is possible: An increase in the time interval between training and test should produce an increase in relative choice; a decrease in the time interval should produce an increase of absolute responses. This is just what Köhler found.

So far we have dealt with the case in which (in terms of the first structure) $x = b$, and y is a strange, new stimulus to which no response has been learned. The conditions are perhaps still similar if we choose situations in which x does not equal b, but the difference between x and b is much smaller than that between x and a, or the difference between y and a or that between y and b. If we suppose that the animal looks only for the smallest difference, in terms of the first structure he should still choose x and not y when b was the positive training stimulus.

But what happens if we try to take all four distances into account (see Fig. 4)? The situation becomes complicated, because x and y are both nearer to b than to a. In order to explain the reaction to x as to b, we would have to introduce complicated mechanisms concerning the differences of the distances.

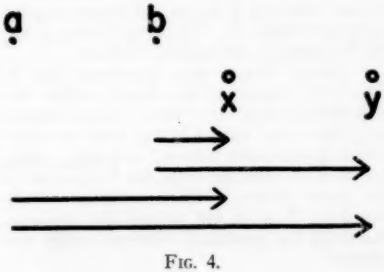

FIG. 4.

COMPARISON OF LOGICAL STRUCTURE II AND SPENCE'S TREATMENT OF TRANSPOSITION; CRITICISM OF ATTEMPTS TO AVOID THE EFFECTIVENESS OF RELATIONS

a. The main difference between our second logical structure and Spence's (1936, 1937) formulation, which is based on the first logical structure, is that Spence's scheme tries to avoid at all cost any effectiveness of the relation between a and b or the relation between x and y.[7]

This avoidance is all the more striking because Spence uses the relations or distances between a and x and between a and y as basic to his theory; time factors and the demand placed upon memory make use of such relations very much more difficult.

Some psychologists seem to be somewhat suspicious about the reality or effectiveness of actual relations within constellations of stimuli. For them, the problem is something of a riddle, or something to be put in the category of "achievements of intelligence," "higher mental processes," and so on. Certainly there are some important and interesting connections between "intelligence" and "use of relations." But entirely apart from this, effectiveness

[7] *Spence attempts to explain discrimination learning by the building up of excitatory tendencies to the positive stimulus, responses to which are reinforced, and inhibitory tendencies to the negative stimulus, responses to which are not reinforced. Certain curves of generalization are postulated for each of these tendencies. The effective excitatory strength of a stimulus depends upon the amount by which the total excitatory tendency exceeds the inhibitory, and the choice between the two stimuli is dependent upon the difference between their effective excitatory strengths. This theory is dealt with in detail in Wertheimer's second paper.*

of relations seems required by the facts, and in fact relations demand *less of memory* in simple discrimination experiments than do absolute qualities.

Suppose an animal reacts relationally in a test trial. For that, it does not need exact memory for the absolute qualities of the training stimuli, nor (under most circumstances) memory for the exact size of the relation. Mostly nothing else is required than choice *in the direction of* the difference, parallel to the direction learned in the training pair. Why should we presuppose a level of exactness for memory, recognition of the absolute qualities of the training stimulus after a long time delay, if so much less seems demanded by the facts? As we have mentioned before, exact memory for absolute qualities after a long time interval is a very much higher achievement, is much more poorly performed, and often demands long and specific training. To recognize, or to respond by going to, the brighter or higher stimulus demands very much less than to recognize the identical gray of the preceding day.[8]

b. Let us try to clarify the theoretical situation by considering in what ways actual relations may come into play and become determining for behavior.

1. What happens in the time during which the animal looks from one stimulus to the other on the test trials and also on the training trials?[9]

Looking from one stimulus to the other may mean, to begin with, a very concrete physiological fact. For example, let us say that *a* and *b* are two boxes, equal in every way except that they are placed at different heights, *b* higher than *a*. The animal, in looking from *a* to *b*, lifts his head, or his eyes, and lowers them in the transition from *b* to *a*.[10]

In the test situation *y* may be identified with *b* on the basis that both are "what is reached at the end of the lifting." For transposition performance in test trials, there is no need to remember the absolute position of the boxes, the exact size of the difference in height, or the extent of the movement. As long as the test situation is at least to some degree similar to the training situation in this respect, the transposition reaction may follow simply from the animal going toward the stimulus reached at the end of the lifting, as he has learned; such a response would be based on the actual relations in the constellation.

Or *a* and *b* may be two squares of different area. Then the animal may lift its eyes from the top of the lower square to the top of the higher, and base its response on this process.[11]

[8] Spence's generalization formula bases choice in test trials precisely on the *exact constancy* of the excitatory and inhibitory tendencies connected with the absolute qualities, and so demands basically much more than is needed, or seems probable.

[9] It has to be kept in mind that for the first logical structure the animal, on seeing the stimuli in the test pair, looks for a comparison of *x* and the traces of *a* and *b*. He does not look for a relation between *x* and *y*, but for a relation between *each* of these and the traces of *a* and *b*—a comparison of two items with a long time interval between them.

[10] There may be a possibility that by chance, or through training, an animal will do it the other way around—that when he looks at the lower box he will focus above it, and when he looks at the upper one, he will focus below it. But this certainly is not the probable or the natural tendency.

[11] Similar factors may sometimes play a role with regard to the forms within the stimuli (see Fig. 5). Here, while looking at *a*, there may occur a lifting from the horizontal to the point "above," and while looking at *b*, a lowering from the horizontal to the point "below." Here lowering occurs not from *b* to *a*, but *within the stimulus*, based on the positional relations within the stimulus.

Instead of simple lifting of the head or eyes from one stimulus to the other, there could be eye movements with reference to each stimulus, differing in the range of movement in accordance with the size of the stimuli. Suppose the animal responds with reference to the length of the bases; it might have to make a larger eye movement in following the larger square. Instead of lifting, this increase in the eye movement from *a* to *b* could be decisive and sufficient.

Similar things may play a role in *brightness* differences with regard to adjustments of the eye in the transition from dark to bright. Again, it seems that recalling, recognizing, reacting in the same way to such a direction of a difference is very much easier than recalling, recognizing, etc., the absolute size or brightness.

Such things as lifting the head, etc., are themselves connected with and based on the fact that two stimuli are essentially different in a certain way, that they are connected by a particular relation. In all the cases that have been under consideration, the movement that the animal makes, or the animal's transitional experiences, are determined not simply by an arbitrary connection, but by the actual relational qualities of the optical or optical-motor situation. The moving of the head is not something added to the separate stimuli, but is itself associated with a relation between the stimuli. This alone seems already to imply the reality and significance of the relation within the stimulus pair. Such behavior, then, is not based on an *arbitrary* learned connection to some relation, but is, in regard to its content, in agreement with the actual nature of the relation. Lifting the head or eyes when viewing two boxes at different heights, for example, in turning from one stimulus to the other, is a consequence of the relative height of the two boxes, and is not connected with them arbitrarily.

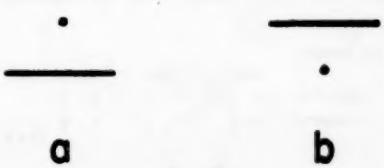

FIG. 5.

What we have just said involves two not necessarily dependent points. First: The behavior may be connected, not with one stimulus, or with the other, or with one "and" the other, but with the relation between the stimuli that make up the pair. Second: At least from the point of view of the animal, there is an inner connection—and not an arbitrary one—between the stimuli and the movement.[12]

Transition phenomena may physiologically also have importance when viewed simply as events in the *optical field*. For example, in the change from a small white circle on a gray field to a large white circle in the same place on the gray field, there is the process of "widening the bright region." Again the positive stimulus may become "the stimulus at the end of the widening."

2. Such transitional events may not be a necessary condition for learning and transposition. Instead of such transition-phenomena, a *whole-quality*

[12] That in the transition from the lower stimulus to the higher, one lifts the head or the eyes, and that wider movements happen on the side of the wider stimulus, and not the other way around, is somehow obvious but not, on that account, less interesting theoretically. Of course, one could try to teach the opposite reaction—no doubt a difficult and senseless enterprise. The theoretical problem is not settled by calling one of the two behaviors simply innate: the "innate" response shows in these instances precisely the logically outstanding, materially sensible direction.

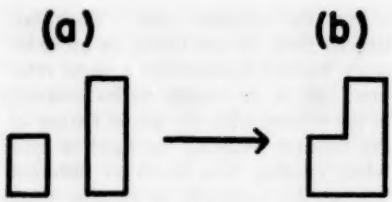

FIG. 6.

(connected, for example, with a disturbance of balance in a certain direction, being top-heavy, being overloaded on one side, etc.) may determine the behavior or the attitude, and thus the response. Under certain conditions there is the possibility that the animal, without necessarily shifting from one to the other while facing both stimuli simultaneously, would experience a disturbance of balance in one direction, such as the weight tending towards the right. Such experiences *may* be connected with real movement, or with real movement-tendencies, or with tonus-distributions—or, even *before* all this, they may have a reality in the optical field. This becomes all the more possible if we do not envisage the central effects of optical stimulations as a piecemeal sum, but with reference to the distribution of energy in the brain.

The preceding point touches upon the odd problem of what constitutes "one" stimulus. It seems to suggest that "two" stimuli may essentially at first have the effect of one stimulus-constellation. This becomes very clear if we consider, in Fig. 6, a change of the experimental situation from (a) to (b).

3. If learning and transposition were determined by the features we have mentioned—by transition phenomena and by the whole-qualities of stimulus constellations—this would demand very much less of memory in test trials than if the events were based on the piecemeal, absolute qualities. The *direction* of the movement, for example, not its *exact size,* would be decisive. Memory of the direction of the difference in height, for example, and not the exact amount of the difference, would be required.

CONDITIONS FAVORING TRANSPOSITION OR ABSOLUTE REACTION

As we mentioned above (in the sections on "Ability Distinguished from Attitude," "Logical Structure II," and "Conditions Under Which the Two Logical Structures Work in Opposite Directions"), there are attitudes and experimental set-ups which may increase the likelihood of either absolute or relational choice. There is, for example, the possibility that the animal is "interested" only in the positive stimulus, thus recognizing it better than the negative stimulus; or the animal may, in the test trial, be initially concerned only with *one* of the stimuli given. It seems reasonable to recognize both absolute and relative behavior attitudes as two possibilities, at least in some cases, as Köhler (1918) did. Both logical structures must be studied as possibilities, and their implications put to test. (And we may need to add some other possibilities of attitudes and structures as well. The present experimental situation seems to call for the study of the different attitudes which favor one outcome or the other.)

a. Certain sequences of learning trials can help transposition or absolute reaction (Fig. 7).

b. The choice of the absolute stimulus may be increased when the training

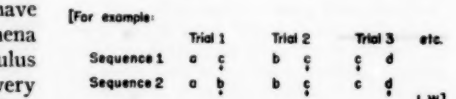

FIG. 7.

and testing pairs are separated by a relatively short time interval (Köhler, 1918). If the time interval is large, relative choice increases. This is especially true if the difference between the training stimuli is very small, in which case it seems to become impossible to recognize whether an *x* is an *a* or a *b* in a test trial.

To explain the effect of the time interval, Köhler has pointed to the difference in the forgetting curve for absolute and relational experiences. It is also possible that "absolute" choice with small time intervals may be the outcome of Gestalt factors. If *b* corresponds in absolute terms with *x*, when the training and test pairs are presented in close succession the three different stimuli of the two pairs form a unit (a triad) in which the "absolute" stimulus occupies a constant relational position, namely, the center (see Fig. 8).

c. The distance between the two stimuli composing the pair is also an important factor. Decreasing this distance probably increases relational choice.

A time interval between *a* and *b* in learning (and similarly between *x* and *y* in testing), especially when other stimuli are introduced between them, could work against the relational attitude and for the absolute attitude (Jackson, 1943).

Generally it looks as if all of the factors which tend to make an *unum* out of the stimuli seem to favor the perception of a difference and hence the relational response (see Line,

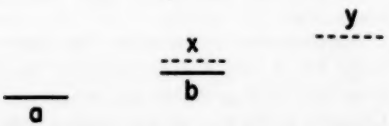

FIG. 8.

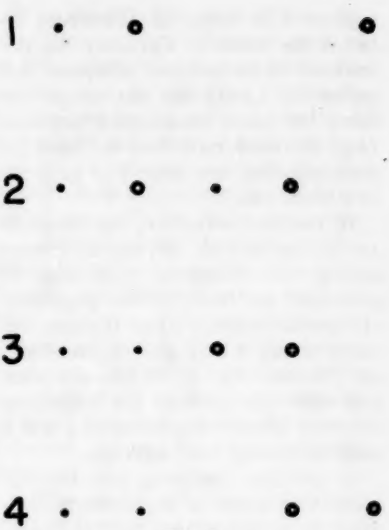

FIG. 9.

1931).[13] An extreme case favoring relative choice is the one where, instead of having, say, two boxes, we have two openings in the same object.

d. If *a* and *b* are special members of a series, the logical structure of the stimulus situation also becomes somehow special. Relational choice may be less likely in such situations.

e. The case $x = b$ (Line 1 in Fig. 9) is a special case among many possibilities and constitutes the strongest in favor of absolute choice.

f. Extrinsic factors such as preference for a particular stimulus independently of the learning trials may also determine choices.

FACTORS INVOLVED IN EACH OF THE LOGICAL STRUCTURES

a. What is involved in the first structure? In order to simplify, I shall

[13] Cf. Fig. 6. *The points in Paragraph* b *of the section on "Comparison of Logical Structure II and Spence's Treatment of Transposition" are also relevant to this discussion.*

express it in terms of differences between the stimuli. Certainly the differences alone are not adequate, but rather the ratio; and not simply the ratio, but more complicated functions (e.g., the same ratio does not have the same meaning in a large pair as it has in a small pair).

In the first structure, the distances *xa*, *xb*, *ya*, and *yb*, and the differences among these distances (see Fig. 4) constitute the basis for the possibility of discrimination. (The distance between *a* and *b* may also be decisive—see Footnote 3.) In all this one must also take into account the increasing difficulty of the recognition of *a* and *b* with increasing time intervals.

In addition, one must take into account that there is experimental evidence for what one may call *"shifting."* Suppose Tone C is given the first day and learned, and on the next day Tone D is given. In many cases the subject will not be able to judge with certainty whether the two tones are different; under many usual circumstances they will be judged to be the same. But if C is then given after D, C may be judged too low—the D now being taken as the standard (as mentioned in Paragraph *b* of the above section on "The Difficulty of Memory for Absolute Qualities and the Exact Sizes of Relations"). Or suppose that on the second day a number of test tones are given which are in a quite different range than the original tones. Some experiments seem to show that there is a likelihood that the judgments will not be centered around the original stimulus, but around a standard determined by the latter group.

b. What is involved in the second structure? The second structure involves the functioning of the following factors: (1) a perception of a difference between the two training stimuli and also between the two test stimuli; (2) remembering that, for example, the larger, or the smaller, contained food, and choosing on the basis of this memory; (3) the factor of the gradient—if in the test pair the size of the difference is considerably changed, the reaction may become more uncertain; (4) the factor of level—if the level of the whole pair is considerably changed, the reaction may again become more uncertain.

We shall illustrate what is involved in Points 3 and 4, first making again the simplifying assumption that distances in terms of differences would be decisive. Point 3 would involve a function of the ratio of $\frac{a-b}{x-y}$. Point 4, making for the sake of brevity once more the simplest assumption, would involve a function of the means:

$$\frac{\frac{a+b}{2}}{\frac{x+y}{2}} \quad \text{or} \quad \frac{a+b}{x+y}$$

Especially if considerable time elapses between training and test, the probable functions would not presuppose the exact values of *a* and *b*, but would probably be related more to a "region" involving $a-b$ or $a+b$.

If instead of the distance, the *ratio* would be decisive, in 3 we would have a function of the ratio x/y to the ratio a/b. It does not, however, seem probable that the ratio will be decisive throughout, entirely independently of accompanying changes in the differences, etc.

Furthermore, to formulate the functions for 3 and 4 separately, as was done here, will probably not be correct. Changes in the size of the relation will

probably not be entirely independent of changes in level.[14]

These four factors are not simply abstract, logical parts of the picture. They can be studied experimentally, which will make it possible to reach more precise formulations of the kind of functions they involve.

Factor 1. Here belong experiments in which the distance between the pairs is systematically decreased during teaching or during tests, until the threshold is reached. Comparably, one might present pairs of different degrees of closeness. A direct experimental procedure would involve the learning of training pairs in which each of the two "stimuli" is a pair, one consisting of equal parts, the other of unequal ones whose distance is progressively decreased.

Experiments dealing with Factor 2 are discussed below in the last section.

Factor 3. For this factor, one might use the learning of a training pair in which there are different gradients in the relation. Or one might change the gradient after learning (perhaps after the use of training pairs of the kind suggested in connection with the study of Factor 1).

Factor 4. For this factor, one could change the level after learning of the training pair, or have the subject learn with pairs at different levels, using again a pair for each "stimulus."

Of course, what we have said here still involves major abstractions, because of a number of points such as the following: (*a*) relations within the situation may be effective; (*b*) saying that we are dealing with a relation is not entirely sufficient—it seems to be a question of structure as well as relation: whole-qualities, such as the direction of disequilibrium, may play a role; (*c*) the "absolute" qualities of the stimulus do not seem to be simply absolute qualities—probably they involve relations with the framework, background, etc., in spite of the latter's constancy. All of these seem to fit into the picture, mainly only introducing some complication into the scheme indicated above for the relational formula.

I hope to be able in a subsequent paper to discuss the steps involved and to describe also the logical structures involved in the experiments of Lashley.[15]

The next section was in very unfinished form. The following is my interpretation of what was intended.

ATTEMPTING A COMMON FRAMEWORK FOR TRANSPOSITION AND ABSOLUTE REACTION

[The two logical structures described were conceived, to begin with, in order to do justice to different kinds of behavior—the first logical structure for absolute reaction, and the second for transposition. The real problem is to identify the conditions which favor one or the other. If, in spite of this, one wants to envisage a common framework for both, what is the situation?

[One could try to understand both absolute reaction and transposition in terms of the first logical structure. There are some obstacles to this. First:

[14] On the basis of these four points, formulations for the general function determining the results in test trials are mathematically quite easy. K. O. Friedrichs, at my request, developed some. But I think it is not worth while to propose a particular formula at the present stage. In order to choose one sensibly, one would first have to know more about the factual character of the function with respect to changes in the gradient and the level.

[15] *This paper was, to my knowledge, never written.*

The four differences $x-a$, $x-b$, $y-a$, and $y-b$ would have to be taken into account—and one would have to introduce complicated mechanisms concerning their role. Second: One must remain aware of the effects of time between training and testing, and the other factors which affect relational or absolute reaction. Third: Relations between present stimuli and the traces of earlier ones, upon which the first structure relies, are much more difficult to use than relations among simultaneously present stimuli. Fourth: One cannot in any case leave the difference between two stimuli of a pair ($x-y$ and $a-b$) entirely out of consideration, since a positive response to one and a negative response to the other may be aroused only if they are sufficiently different to be reacted to *as* different.

[To attempt to account for both absolute reaction and transposition in terms of the first logical structure thus involves a number of difficulties. What happens if we look at the situation the other way around—could both kinds of reactions be understood in terms of the second logical structure?

[The second structure was first conceived in an attempt to account for relational choosing. But consider what happens in terms of this structure, as an extreme case, when only one stimulus is presented. Then of the four factors in Structure II, only the level remains—coinciding now with the nuance of the stimulus. Similarly, if there is a stimulus pair but the attitude is such that the animal is concerned only with the one, say the positive stimulus, the logical factors are the same. Again only the level remains—and absolute reaction should follow. The level will also be the only critical factor when with a pair of stimuli the attitude involves looking for the one *and* the other—an and-summation; here again absolute and not relational choosing should occur.

[Logically, as the importance of the relation within the pair approaches zero,[16] we get a special case of Structure II, which leads to absolute rather than relational choice. Both kinds of reactions may thus be understood in terms of the second logical structure. The main task of the experimenter seems to be to study the conditions under which the restriction of factors that leads to absolute reaction takes place.]

ARBITRARINESS AND NONARBITRARINESS IN DISCRIMINATION LEARNING

At the end of this paper there is a further discussion of the factors that Wertheimer felt were involved in the typical discrimination experiment. The essence of this discussion seems to be the following:

[The first, third, and fourth factors of Structure II (see p. 262) are concerned with the actual nature of the items involved. The order from smaller to larger, for example, is not an arbitrarily changeable learned order (as is, e.g., the alphabet). On the other hand, the second factor, the way in which most experiments are set up, represents an arbitrary connection to be learned only by induction; whether food is obtained through *a* or through *b* depends simply on the arbitrary choice of the experimenter, and thus involves a "blind" connection, having the character of classical associations.[17]

[16] The *attainment* of zero is not admissable, because of the point mentioned about reacting to the stimuli as *different*.

[17] [There is, however, a certain "nonarbitrary" factor involved here also; although *which* of the two stimuli is the "right" one is arbitrary, the stimulus is always made to be not only the sign for the response but also the sign for the *location* of the response. If only an entirely arbitrary connection be-

[The arbitrariness of the "right" stimulus is alterable. For example, the discrimination stimuli might be two square holes in a grating, one small and one large, with food placed in an intermediate size box behind the grating between the holes so that one would have to reach through the larger hole. Or the stimuli might be a wooden triangle and circle, a child having to learn to take the triangle and fit it into a form board with a triangular hole. These cases involve outstanding ρ relations (cf. Wertheimer, 1945). One could also perform experiments reversing these requirements: e.g., by mechanical devices, the food box might be made to go through only the smaller hole; the triangular formboard hole may be made so as to adjust itself somehow only to the circle. If the first kind of set-up involved nothing but the learning of truly arbitrary connections, then there should be no difference between the learning in these two kinds of situations.

[Many psychologists may feel that the difference between the learning in the two types of situations will be due to nothing other than previous experience. One may then ask whether this is really certain, or just a dogmatic belief. The main point, however, is not whether they are due to experience or not. They may be, but then two different *kinds* of experience are involved: experiences governed by a certain kind of logical structure, governed by ρ conditions, and experiences from which logical structure is excluded.]

tween some stimulus and some response were involved, an animal should learn in just the same way and just as easily to respond, say, to a place seven inches to the right of the positive stimulus.]

SUMMARY

This was the end of the paper as far as Wertheimer completed it. A brief summary may, however, be helpful.

[One may attempt to understand learning to respond correctly in discrimination experiments on the basis of two different logical structures. In Logical Structure I the correct response occurs on the basis of recognition of absolute qualities. The essential factors involved here are the differences between each of the members of the test pair and each of the training stimuli.

[In Logical Structure II the correct response occurs on the basis of recognition of position in relational structures. The main factors involved here are the relations within the training pair and within the test pair; the level of each pair also plays a role.

[The kind of memory called for in Logical Structure II—primarily, the direction of relations—is very much easier than the memory of absolute qualities required in Logical Structure I, particularly if there is any appreciable time lapse between training and test. A number of factors are discussed which favor absolute or relational reactions.

[The question is raised whether both kinds of reactions may be understood in terms of either logical structure alone. To attempt to explain relational choosing in terms of Logical Structure I leads to a number of difficulties. Effectiveness of relations between old stimuli and present ones is assumed, while that of relations among simultaneously present stimuli is avoided. The attempt to avoid effectiveness of relations in constellations of stimuli is criticized.

[How such relations may become effective and what conditions favor their effectiveness is discussed. Under

certain conditions, such as when there is concern with only one stimulus, the role of relations becomes minimal. In these cases only the factor of level in Logical Structure II remains critical, and this would lead to absolute reaction. Thus Logical Structure II may account for absolute choices as a special case—as well as for relational ones.]

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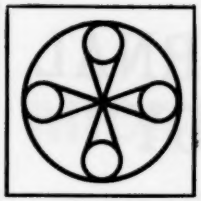

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